THE MAINTENANCE OF SOIL FERTILITY

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CHARLES E. THORNE

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WHEAT IN BROADBALK FIELD, ROTHAMSTED, ENGLAND

The Maintenance of Soil Fertility

BY

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ILLUSTRATED

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PREFACE

Within the space of a lifetime, by substituting mechanical power for that of man and beast, the larger part of the most laborious work of the farm has been transferred to the city machine shop. This transfer enables the individual farmer of today to cultivate a much larger acreage than was possible in the days of the ox-drawn plow and the arm-powered sickle and flail, but it has not materially increased the produce of the acre nor reduced the cost of the bushel, for the high wages of the men engaged in collecting and transporting from mine and forest the raw materials from which the farmer's machinery is constructed and in building that machinery, together with the multitudinous overhead costs of superintendence, equipment, taxes, interest on investment and depreciation in value of machinery, all must be covered in the cost of the farmer's machine, together with the higher wages he must pay for the labor it is still necessary for him to employ. The outcome therefore has been that, whereas in the days of the sickle and flail a bushel of wheat was the ordinary compensation for a day's labor on the farm, from two to three bushels are now required to pay for the same service.

Moreover, while the individual farmer of today, with the aid of his machinery, is producing several times as much food as did his grandfather, by the time the proportion of that food required for the support of those directly and indirectly engaged in the building of his machinery is set aside there is little more left for those engaged in other vocations than was the case in the earlier day. The fact that we still have food in abundance for our increasing population is due to the constantly enlarging area that the development of farm machinery and of means of transportation have enabled us to bring under cultivation.

But while the only limit to increase of population is the supply of food, the land is definitely circumscribed. Eng-

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land has long been an importer of food, and the same is true of much of continental Europe. Taking Ohio as a typical American State, during the decade 1850-1859—the closing years of the sickle and flail—this State produced eleven bushels of wheat for each person of its population, while during the decade 1910-1919 the average production was less than five bushels per capita, and during the decade just ending the State has probably imported more wheat than it has exported, and this notwithstanding all the advantage given by improved machinery.

While inventors have laid forest, mine and machine shop under contribution to substitute steel and electricity for muscle and nerve, another group of explorers, working with test tube and microscope, have been revealing the laws governing the nutrition of plant and animal.

The scientific laboratory on the one hand and the experiment field and feeding stable on the other are the right hand and the left hand of effective research in agriculture.

Until the chemist's laboratory had shown that the foundations of the living structure, whether of plant or animal, consist of certain elementary substances in the soil, and that growth consists in the transfer of these substances as a nucleus to the structure above, the work of crop or animal improvement was but a groping in the dark.

But it is one thing to know that certain elements or elementary substances are fundamentally necessary to the growth of plant or animal, and an altogether different proposition so to employ this knowledge as to produce economical results.

It is not possible to duplicate in the laboratory the conditions of soil, subsoil, rain, frost and sunshine that prevail in the field under varying seasonal conditions, nor to deal with sufficient numbers to counterbalance the variations due to individuality, but until this is done the teaching of the laboratory may be an even less reliable guide to the farmer than the empiricism that preceded it.

Nor can this confirmative work be left to the farmer, for effective field experiment is one of the costliest and most tedious and difficult forms of scientific research. An experiment limited to a single soil or to a few seasons may be altogether misleading in its indications; it is only when the effects of different treatments on the same soil and of similar treatments on different soils are compared under scientific observation, and when these comparisons are continued throughout a cycle of changing seasons, that we may be reasonably confident in our interpretation of results.

The work of the laboratory is the qualitative test, which demonstrates the presence of certain factors in the problem, and may serve for an approximate estimate of their relative importance; but there are factors which can not be measured in the laboratory and which must be included before we can have a quantitative solution of the entire problem of fertility maintenance.

The work of the laboratory is the reconnaissance survey, by which the practicable route is indicated; but this survey must be followed by the costly work of the construction engineer before the route can be utilized by the traveler.

The work of the laboratory is the architect's picture, in which he shows the different parts and relative proportions of the building; but this picture must be replaced by the solid materials of construction, all carefully fitted to their places and purposes by skilled artisans before it can become a habitation.

The qualitative test, the reconnaissance survey, the architect's picture, are the indispensable guides, without whose aid the work of the analyst and builder must be done blindly and at random; but unless the guides are followed by skilled engineers and builders their work is of no avail.

If, therefore, it may seem that in this volume special stress is laid upon the work of the experiment field, rather than upon that of the laboratory, it is not because of lack of appreciation of laboratory research, but because of the desire to interpret the results of that research in terms of actual farm practice.

Effective field experimentation is still in its infancy. Much of the earlier work was defective because of lack of experience in the methods essential to the securing of trustworthy results: it has been difficult to obtain adequate support for such work; and there have been many interruptions, due to changes in personnel and consequent changes in plan or conduct of the work. It has therefore seemed better to confine the present discussion chiefly to results obtained in experiments of considerable duration made on a few representative soils than to attempt a complete digest of all the work under way.

It is encouraging to note that the necessity for this work is being more widely recognized. New work is being undertaken along comprehensive lines, and the indications now are that the time is coming when the problem of fertility maintenance may be treated in a far more adequate manner than is possible today.

The work thus far accomplished, however, has demonstrated that the farmer now has it in his power very materially to increase the yield of the acre, and at the same time to reduce the unit cost of production, through methods, some of which have become available since the beginning of the present century.

Not only are the economic conditions of the farm constantly changing with the improvements in farm machinery and the changes in transportation and marketing, but the soil itself is moving. Twenty years ago this book could not have been written. Twenty years hence it will be necessary to rewrite it. Meanwhile it is offered in the hope that its interpretation of our present knowledge of the soil may be of service, both to the student of the principles governing the maintenance of soil fertility and to the working farmer on his farm.

Charles E. Thorne

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The Maintenance of Soil Fertility

I

The Soil

The Soil, in the agricultural use of the term, is the thin, superficial covering of the earth through which the greater proportion of plant roots range in their search for nutriment and water. It is usually but a few inches in thickness, varying with its composition and drainage when uncultivated, and with the depth to which the plow is run on cultivated land. It is darker in color than the stratum below, to which the name *subsoil* is applied, this darker color being due to the presence of decaying organic matter, such as plant roots and other residues and insect and animal tissues and excrement. It is the storehouse of the available mineral and nitrogenous elements of the food of the plant, and the laboratory within which are effected the transformations by which these elements are separated from their original inert combinations, and recombined in forms suitable for plant nutrition. It is the reservoir within which the water supply of the plant is maintained.

The subsoil lies below the soil and rests upon rock, gravel or sand, or upon compacted clays, known as hardpan and bowlder clay. It is usually firmer in texture than the soil and lighter in color. It may be a few inches, or many feet, in thickness. It is a potential storehouse of mineral plant food, which is locked up in unavailable combinations until liberated by the physical, chemical and biological transformations which take place in the upper soil.

Rocks the origin of the soil—Soil and subsoil were originally derived from the same source, the rock crust of the earth. Their difference now is due to the action of chemical and biological agencies, working in that portion of the surface to which air has had access, and working through uncounted ages of time. Some of the factors in soil formation are briefly enumerated below.

THE MINERAL BASIS OF THE SOIL

The lichen growing on the face of a cliff seems a very insignificant thing; but when the lichen has completed its existence and falls to the ground it carries with it a minute portion of the substance of the rock, which it has absorbed through its rootlets and built into its tissues. All living things, whether plant or animal, require a mineral basis upon which the organism as a whole is constructed. The work of the single lichen is too small to be measured by ordinary instruments, but when billions of lichens are given eons of time for their work they may move mountains.

The wind, when it gathers up the desert sand and hurls it against the face of the rock, exerts a force more easily appreciated than that of the lichen, for we have learned to harness the wind and with it drive the modern sand blast. In the arid regions are to be found many examples of outstanding rocks which have been ground into fantastic shapes, and many cliffs whose faces have been pock-marked by this action of the wind; but it has performed a still more important function in the transporting and redepositing of dust and sand. The cloud of dust which precedes a gathering storm may be deposited in a film too thin for measurement, but when such films are multiplied by millions they may become many feet in thickness.

Frost assists in breaking down the rocks. When water penetrates the crevices between the rock strata, or those left by decaying roots, and freezes there, it causes flakes to split off or even large stones to be loosened. The talus, or sloping heap of rock fragments usually found at the foot of a cliff, has been largely formed by the frost in this manner.

Sunshine assists in the disintegration of rocks by causing expansion of their surface particles. As the different minerals of which some rocks are composed expand and contract differently under heat and cold the effect is to cause a scaling off of the surface. The effect of the sun's heat upon rocky material is illustrated in the heaving up of brick or concrete roads, when insufficient allowance has been made for expansion.

Rain beats upon the rock and carries the particles loosened by lichen, wind, frost and sun to lower levels, there to be spread out in beds of sand and silt and clay. Each muddy streamlet flowing down the hillside, though no larger than a pencil, is helping to move the mountain to the plain.

Moving ice has been a potent factor in the grinding up and redistributing of rocky material. At one time the glaciers which now cover most of Greenland and immense areas in Alaska were of continental proportions, reaching southward in many places to or even beyond the fortieth parallel of latitude. These glaciers are sheets of moving ice, their motion being due to the combined forces of immense accumulations of snow in the north or on their higher elevations and the melting of their lower or southern exposures, the weight above pushing them forward as the lower portion melts away.

Glacial moraines—In their progress the glaciers carry with them fragments of rock torn from the mountain side and from the floor over which they travel, grinding these together and finally depositing them, as rounded bowlders, gravel and sand, in low ridges running transversely to the path of the glacier. In many places the surface of the rock now shows the tool marks of the glacier, caused by hard stones being held in its grip and scratching the rock over which it has moved. The terminal moraines, which the ridges of gravel and sand are called, mark the places where the end of the glacier stood for many years, until the increasing warmth drove it backward to a more northerly stand.

Glacial drift—As the ice retreated northward it left not only the terminal moraines, but also great sheets of a mixture of gravel, sand, silt and clay, brought by the glacier and deposited in the shallow sea which for a time stood between its foot and the moraine marking its previous stand.

The drift, as this ice-borne material is called, is made up of beds of gravel, sand and clay, or of an impervious blue clay in which rounded stones are imbedded and which is called bowlder clay, the deposits ranging from a few inches to hundreds of feet in thickness.

Non-glaciated soils—Beyond the range of the ice sheet the materials resulting from the weathering of the rocks remained in place, giving rise to the class of soils known as sedentary, or residual, soils, as distinguished from those soils the mineral foundation of which has been transported by water, ice or wind.

Rock elements are but the skeleton of the soil—By such agencies as these, working through the countless ages of the past, the surfaces of the rocks have been ground into sand and silt and clay, and these have been spread over the earth in a thin layer to form the basis of the soil. This powdered rock, however, is not soil; it is merely the skeleton of the soil.

Certain rocks contain large proportions of the mineral elements essential to the growth of plants. One of the feldspars, (Orthoclase) for example, is a silicate of aluminum and potassium, containing about 11 percent of potassium, or about twice as much as is found in wood ashes. Another feldspar (Albite) contains sodium instead of potassium. Dolomites are limestones, chiefly made up of the carbonates of calcium and magnesium.[1] Apatite is a widely distributed rock, containing phosphorus combined with calcium and also containing chlorine and manganese in some of its varieties. Pyrites, a common mineral, one form of which is often mistaken for gold ore, is a compound of sulphur and iron.

The food of the plant must be dissolved in water—Out of these rocks, ground to dust, might be made a mixture containing all the mineral elements required for the most luxuriant growth of vegetation; in fact, such rocks are the original source from which has been derived all the mineral substance found in plants, animals and man, but before the rock dust can become a soil, in the proper meaning of that word, it must be converted into a different form from that of the original rock; for the plant has no stomach, into which it may take its food and there dissolve it by its own secretions, but that portion of its nourishment which it obtains from the soil must be presented in such condition that it may be absorbed through the delicate membranes which cover the tips of the almost microscopic rootlets, and must be maintained in constant supply and of approximately uniform composition.

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[1] The formula for dolomite, $Ca,MgCO_2$ would indicate 30.4 parts calcium oxide and 21.7 parts magnesium oxide, but there is considerable variation in the proportions of the two carbonates in the magnesian limestones.

Remembering, however, that the soil must continue to furnish its annual harvests for the sustenance of an ever increasing population, it is easy to understand that its store of potential food must be held in a very slowly soluble form, otherwise it would have been washed out and carried to the sea ages ago, and the earth would have remained a desert.

The food of the plant must be in combination—Men require for their nourishment the same elementary substances that are found in plants, but we cannot utilize these substances in their elementary forms, nor in their simpler combinations, with the single exception of water. Our bones are composed chiefly of a combination of phosphorus, oxygen and calcium, to which we have given the name calcium phosphate, or phosphate of lime, and phosphate of lime is a very efficient fertilizer for plants; but we cannot digest it until the plant has first elaborated it into more complex substances.

Nitrogen is essential to the existence of every living cell, whether of plant or animal; and although nitrogen constitutes four-fifths of the air we breathe, neither we nor the plants which produce our food are able to utilize atmospheric nitrogen. Before our crops can make use of nitrogen it must be combined with oxygen in nitric acid or with hydrogen in ammonia, and before we can assimilate it these combinations must enter into the complex proteid substances found in the plant.

Rock dust is not soil—The mere grinding of the rocks into dust, therefore, does not constitute a soil capable of supporting food-producing vegetation. There must be some process by which the rock dust may not only be dissolved, but by which its constituents may be re-combined in other forms.

At one time this process was believed to consist simply in the solution in the soil water of the rock compounds and the absorption of these compounds by our crops; but we now know that the soil is inhabited by many species of microscopic organisms, whose function is to combine the crude elementary substances of air, water and soil into more complex forms, upon which the higher plants subsist; these soil organisms standing between our crops and the crude elements, much as the lower animals stand between us and the grass of the field.

Organic matter is necessary to complete the soil—Through the action of these organisms, which will be further considered in another chapter, and the accumulation in the soil of the residues of plants and animals, which for ages have lived upon the land and returned to the soil again, there has accumulated in the soil a quantity of organic matter which plays a very important role in the support of subsequent life. This organic matter (called organic because it has once constituted a part of living organisms) is found in all gradations, from the partially decomposed roots of the previous season's vegetation to a black, formless substance, to which the term humus is applied. This organic residue serves as a storage battery in which is accumulated a mass of material that, having once been incorporated in living tissues, is in condition to serve the same purpose again with comparatively little transformation.

The well known fertility of soils rich in organic matter has led to the assumption that such matter possesses a value additional to that of the nitrogen and mineral elements which it carries, but it will be shown in another chapter that this assumption is not correct.

THE DIFFERENT KINDS OF SOIL

Calcareous and non-calcareous soils—As all soils have been derived ultimately from the rocks which form the crust of the earth, the first problem that arises in the attempt to classify a given soil is to determine its geological history, and the character that most definitely separates the rocks, with reference to the soils to which they give rise, is the presence or absence of carbonate of lime.

Long before scientists had studied this question farmers had learned to differentiate between soils along this line of cleavage, a calcareous or "limestone" soil being everywhere regarded as superior to one deficient in this constituent.

Residual and transported soils—The second natural point of division between soils relates to their mode of formation. Some soils have been derived from the rocks which lie beneath them, by the gradual decomposition of these rocks under the influence of the forces included in the term "weathering," while others have been removed from their original point of formation and deposited in other localities through the action of water, wind and moving ice. These two secondary subdivisions in soil classification are described on the one hand as *residual,* or *sedentary* soils, and on the other, as *transported* soils.

Aquatic soils—A third class of soils has been formed in shallow waters by the growth and decay of aquatic vegetation, mixed with more or less sand and clay brought in by the wash from higher lands adjoining. When the excess of water is removed, by drainage or by diking off the sea, there results a soil in which the organic matter constitutes the major portion, instead of being a minor constituent, as in normal soils. On withdrawal of the water and exposure to the air the surface of a marsh land gradually assumes the character of humus or "black matter" and is given the name *"muck,"* while the underlying strata may retain the fibrous character and brown color of *"peat."*

Where the adjacent lands are non-calcareous, the mucks will be deficient in lime, but in limestone regions they may be so well supplied with lime as to have supported, while in the marsh condition, a growth of shell-bearing animal life, the remains of which have accumulated in beds of marl underlying the peat. These marl beds are sometimes of considerable thickness, and offer an excellent source of lime for soil amendment.[2]

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[2] Another calcareous deposit also known as marl is produced by the spray from water highly charged with lime coming in contact with the carbon dioxide of the atmosphere, the result being carbonate of lime. In a small way this is observed in the incrustations of the teakettle or steam boiler in which hard water is used, and in a larger way in the extensive deposits at Castalia and Yellow Springs, Ohio; near Covington, Virginia, and in many other places.

Alluvial, colluvial, glacial and aeolian soils—The transported soils are subdivided into *alluvial* soils, which constitute the flood plains or "bottom lands" of rivers, and are sometimes of vast extent; *colluvial* soils, which have been formed by the sliding of soils down mountain sides, either in avalanches or in the slower movements of talus formation;[3] *glacial* soils, which have been formed by the action of moving ice, a force which has covered many hundreds of thousands of square miles with sheets of clay, usually containing rounded fragments of stone and often alternating with extensive beds of sand and gravel; *aeolian*, or wind-driven soils, which include the sand dunes of seacoast and desert regions and also immense areas that have been covered with an almost impalpable dust, picked up by the wind in periods of drought and redeposited in sheets which sometimes reach a thickness of many feet, and to which the name "Loess" has been given,[4] and *volcanic* soils, formed from the ash which in some cases covers thousands of square miles in volcanic regions, occasionally reaching many feet in thickness.

Sands, silts, loams and clays—The residual alluvial, colluvial and glacial soils may be subdivided into sands, silts, loams and clays, the distinguishing characteristics being based upon the proportions and fineness of the rock particles and the amounts of organic matter present. These subdivisions gradually shade into each other through intermediate forms, described as sandy loams, clay loams, etc.

Climate has exerted a potent influence in soil formation, the soils of humid regions containing, as a rule, smaller quantities of available fertilizing elements than those of semi-arid and arid countries, because of the leaching action of rain; hence it is important to consider climatic as well as geological conditions in determining the agricultural relations of a soil.[5]

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[3] In mountainous regions there are frequent fan-shaped accumulations of detritus which has been carried down through gaps in the mountains and deposited as an overlay in the plains below. Such soil differs from alluvium in its coarser composition and in its topography, which is high and sloping, whereas that of the flood plain is flat.

[4] At first thought it is difficult to comprehend that a cause so insignificant as the cloud of such dust as blows from a country road should be able to produce a deposit a hundred or more feet in thickness, as are some of the loess bluffs along the Mississippi River; but when it is remembered that this cause has been at work for hundreds of thousands, perhaps millions, of years it is more easily understood. To illustrate: it is easy to imagine a sheet of dust as thick as a sheet of the paper on which this book is printed; if 100 dusty days occurred during a summer the year's accumulation would amount to a third of an inch, and in a thousand years, which is but as "a watch in the night" in geologic time, would reach a thickness of 30 feet.

The general outlines of soil classification are indicated in the following diagram:

		Residual......................		Sand
			Alluvial	Silt
	Calcareous		Colluvial	Loam
SOILS		Transported	Glacial	Clay
	Non-calcareous			Dune
			Aeolian	Loess
				Volcanic
		Aquatic......................		Peat

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[5] For more complete discussion of the geologic factors which contribute to soil formation see "Soils" by Hilgard, "Rocks, Rock Weathering and Soils" by Merrill, and "Soils" by Lyon and Fippin.

II

Soils of the United States

As a rule the underlying rock determines the character of the soil, the exceptions being the areas that have been deeply covered by materials transported by ice, water or wind.

The glacial ice sheet extended over New England, northern New Jersey, New York, northern and western Ohio, the northern two-thirds of Indiana, nearly all of Illinois and the territory north of the Missouri River. Over much of this region the glacial drift is composed chiefly of material of similar character to the rock upon which it was finally deposited. It varies in thickness from a few feet to hundreds of feet, and in texture from gravel and sand to clay.

The Coastal Plain—From northern New Jersey to central Mississippi the contour of the land is that of a flat to gently rolling plain, having an average width of approximately 100 miles and an average altitude above the sea of about 100 feet. This plain, excepting Florida, is crossed by numerous streams that have carried down detritus from the mountains and spread it over the land, forming soils in which sand predominates.

The Florida peninsula is topographically an extension of the coastal plain, rising from the ocean and gulf to an elevation of 200 to 300 feet in the middle of the state. The surface rock is limestone which has weathered to a calcareous sand.

The Piedmont Plateau is a belt 60 to 150 miles in width, lying between the Coastal Plain and the Blue Ridge mountains and extending from southern New York to northern Alabama. Its average altitude rises from 500 feet on the east to 1,000 feet on the west through Georgia and the Carolinas, but is lower through Maryland and Pennsylvania. The soil is generally of granitic origin.

The Western Appalachians contain the coal fields of Pennsylvania, Eastern Ohio, West Virginia, Eastern Kentucky, East Tennessee and Alabama, and their predominant soils are clays of non-calcareous origin, but between the ridges lie limestone valleys, the continuous trough containing the Shenandoah, Holston and upper Tennessee rivers being especially noteworthy.

Other limestone areas—Western Ohio and Eastern Indiana are underlaid with a belt of limestone approximately 100 miles in width and extending southward through Kentucky and Tennessee into Northern Alabama and Mississippi.

Limestone occurs again in Northern Illinois and Iowa, but south of this region another coal field is found, reaching into Kentucky, with predominantly non-calcereous soils.

Red soils of the South—South of the glaciated region the rocks have decomposed to a much greater depth than where covered with ice, and the prevailing color of the soil changes from the grays or browns of the northern soils to red, due to the fact that the iron oxide contained in most rocks and which turns red on exposure to air is much less soluble than the other constituents and hence its relative percentage increases.

Loessal soils—Over the central Mississippi Valley, including the greater part of Illinois, western Kentucky and Tennessee, Iowa, Missouri and Arkansas, with local extensions eastward into Michigan, Indiana and Ohio and westward into Nebraska, Kansas and Oklahoma, the land is covered with loessal deposits, apparently due in some places almost exclusively to wind, in others to the combined action of wind and water, and reaching such thickness in many places as to obscure the effect of the rocks from which the basic subsoil has been derived.

Adobe soils—Throughout the semi-arid and mountainous western half of the continent the prevailing soil is a gray-brown or yellowish, calcareous clay, very fine grained and porous, having much the same physical characteristics as the loess, to which the name adobe has been given. Having suffered comparatively little leaching, the adobe soils are usually very fertile, requiring only the addition of water for the abundant production of such crops as are adapted to the climatic conditions.

Alluvial soils—The river valleys are usually occupied by flood plains, the soils of which are composed of the detritus washed by rain from higher lands along the streams. Frequently the valleys are terraced, showing that the streams formerly flowed through broader channels, at higher levels, and in greater volume than at present. In the case of the Mississippi the geological evidence indicates that the Gulf of Mexico once reached as far north as the mouth of the Ohio River, and that a large part of the soils of the adjoining states, from that point southward, has been filched by the tributaries of the great river from the lands to the northward. It is estimated that this river annually carries into the Gulf sufficient sediment to cover a square mile of territory to the depth of 268 feet.[1]

The soils of Ohio—Several of the principal soil formations are represented in Ohio and have been under systematic field experiment for considerable periods. The description of these soils follows, and subsequent chapters will be given to a study of the results attained in these experiments, in comparison with those of similar work in a few other states.

Calcareous and non-calcareous soils—A line beginning at Lake Erie just east of Sandusky, passing through the western limit of Columbus and reaching the Ohio River in southeastern Adams county, separates the soils of Ohio into the two great divisions of calcareous and non-calcareous soils; the predominant surface rocks west of this line being limestones and those east of the line being sandstones or non-calcareous shales, excepting small areas in the coal measures.

Glaciated and non-glaciated areas—Another line, entering the State a few miles north of the entrance of the Ohio River, running westward to the western boundary of Holmes county, thence southward to New Lexington, Perry county, thence southwestward to the Ohio River, south of Georgetown, Brown county, marks the boundary between the glaciated area of the State and that in which the soils, outside of the stream valleys, have been formed by the decomposition of the underlying rocks.

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[1] "Rocks, Rock Weathering and Soils," p. 276.

Practically the whole of the limestone area of the State has been glaciated, but the southward movement of the ice has been approximately parallel to the line of division between the limestones and sandstones, and the major part of the material which it transported was moved for comparatively short distances, so that the glaciation has not materially affected the character of the soil with respect to its lime content.

There is evidence that there were several periods of glaciation, with long intervals between, during which the land became covered with forests and other vegetation, but in the southwestern corner of the State there is a region, including Clermont and parts of the adjoining counties, which did not receive the latest visitation of the ice sheet, but which, during some of the climatic changes of the long ages, became covered with wind-blown dust.

Lake Maumee—Lake Erie at one time occupied a much larger area than at present, extending over a strip several miles wide through the northeastern counties and covering the larger part of ten counties from Erie county westward, together with large areas in eastern Michigan and western Ontario, and having its outlet through the Wabash River at Fort Wayne, Indiana. This old extension of the lake has been named *Lake Maumee* by geologists, and its bottom is a region over which dark or black soils predominate, with sandy ridges marking the successive shores of the lake as it receded into its present basin.

The watershed between the drainage to Lake Erie on the north and to the Ohio River on the south is a broad, flat plain, and at intervals on this plain beds of peat and muck have been formed by the growth and decay of aquatic vegetation in shallow lakes, a formation that is still in progress in small lakes scattered throughout this region and in estuaries of Lake Erie.

Many of the river valleys were much broader in prehistoric time than at present, and their flood plains, formed as the rivers receded into their present channels, especially those of the Scioto and the Great Miami, have formed the basis of a prosperous agriculture.

Principal soil series—Under these conditions many varieties of soil have been formed within the State, and in order so to systematize our knowledge of the soil that the results of studies made on one soil may be applied to similar soils elsewhere names have been given to the different varieties. In selecting these names soils that are similar in geologic origin and physical condition are grouped in a *soil series,* and the series is named for some place where it is a predominant soil or where it was first studied, while soils within a series which are similar in texture are included in *soil types,* the type name being a combination of the series name with the texture of the soil.

In the glaciated shale and sandstone soils of northeastern Ohio three principal series are recognized, the *Trumbull, Volusia* and *Wooster;* the chief differences between which are the variations in the relative proportions of clay and silt, the Trumbull containing the largest proportion of clay, the Wooster the least. Within each series are loams and silt loams. The Trumbull and Volusia series also include clay loams, and the Wooster series, sandy loams and gravelly loams. The one feature that is common to all these soils and which distinguishes them from soils of similar texture in other regions is deficiency in lime.

The *Miami* series occupies the larger part of the glaciated limestone area of the State, the predominant types of which are yellow, calcareous loams and silt loams that constitute the chief soil formations in at least one-fourth of the counties of the State. These soils are derived from gravels, sands and silts resulting from the grinding of the underlying limestones by the glacial ice. In some places the "drift" is many feet in thickness, in others the limestone is near the surface. In places the glacial deposits have taken the form of ridges of gravel, which have weathered into gravelly soils to which the series name "*Bellefontaine*" has been given. The Bellefontaine soils are distinguished from the Miami by a redder color, by having generally a more rolling topography, and by being usually underlaid with gravel or sand, thus giving better drainage.

Next in importance to the Miami soils is the *Clyde* series of brown to black soils, occupying the bed of ancient Lake Maumee and small areas scattered throughout the Miami series, and giving rise to the popular name "black and yellow" for the Miami soils. The Clyde soils range from clay loams to sandy loams. Their color is due to larger accretions of organic residue, resulting from the growth and decay of aquatic or semi-aquatic vegetation in the shallow waters of the slowly receding Lake Maumee, or in the small depressions in the flat lands outside of that area.

The ancient lake persisted for a longer time over the region now occupied by Paulding county than elsewhere, and marshy conditions prevailed until artificial drainage was accomplished on a large scale during the last quarter of the Nineteenth Century. The soil here is brown to black, containing more clay than the typical Clyde series, and is called *Clyde* or *Fulton* clay.

Peat, muck and marl—The same causes that produced the Clyde series have resulted in the formation of the beds of muck and peat that are found on the watershed and in some of the river valleys, the difference in the final outcome apparently being due to an earlier subsidence of the water level in Lake Maumee, after the ice dam across the Saint Lawrence River, which is supposed to have caused the elevation of the lake level, had been melted away, whereas the peat bogs have remained in approximately the same condition of saturation until modern times.

The distinction between peat and muck is that in these bogs the lower strata, being continually covered with water, may still consist of only partially decomposed fibrous matter. brownish in color, while the surface that has been exposed to the air has more completely decayed, losing its fibrous texture and becoming darker in color. Muck and peat, therefore, may be compared to soil and subsoil, both originating in the same source, but the surface being changed by weathering, using this term to include the action of sun, frost and rain and chemico-biologic agencies.

The peat bogs are sometimes underlaid with deposits of marl, originating in the growth of crustaceans and mollusks.

Many mastodon remains have been found in these bogs, the great animals having apparently been mired in them.[2]

Loessal soils—The name *Loess* is given to soils formed from wind-blown dust, or from finely ground rock flour, laid by water. It has a floury feel, when rubbed between thumb and finger, and has a peculiar vertical cleavage, when deposited in thick beds, as shown in the bluffs along the Mississippi, where it faces the river in perpendicular cliffs, 50 to 100 feet in height. In some parts of the Mississippi Valley, and in other regions, notably in China, the Loess is a very important formation. In Ohio it covers a small area in the southwestern corner of the State and beyond the limits of the latest, or Wisconsin glaciation, where a thin sheet of it covers the level uplands of Clermont and adjoining counties, it having been washed away from the steeper hillsides. Two types of loess are recognized in this region, the *Clermont silt loam* in the flatter uplands and the *Cincinnati silt loam* where a more rolling topography has given better drainage. Under the loess the oldest, or Illinoian glaciation, extends to the Ohio River and beyond.

South of the glacial boundary the soils of some 20 counties of southeastern and southern Ohio have been formed by the decomposition of the underlying rocks. Over the greater part of this region the rock has been sandstone, and the resulting soil series is named *Muskingum*.[3] The series includes silt loams, sandy loams and stony loams. Intermixed with the Muskingum soils are relatively small areas of soils which have been formed in part from the limestones of the coal measures and which manifest the presence of limestone in superior productiveness. To these soils the series name *Westmoreland* has been given.

River valleys and terraces—The soils of the river valleys have been formed by the intermingling of detritus brought down by the rivers themselves with wash from the neighboring uplands and are consequently more composite in character than the upland soils. While the glaciers were being driven northward the torrents that flowed from their feet were much larger than our present rivers, and contained quantities of gravel and sand which the glaciers had picked up in their course. This detritus was spread over wide flood plains, forming the basis of the *terrace* soils which are found along the southward flowing streams. With the withdrawal of the ice beyond the lake the volume of water became much smaller and the streams contracted into their present channels. These terraces are one of the evidences that there have been several periods of glaciation. In several places terrace soils are found where no stream sufficient to have produced them now exists, the ancient river having abandoned its course and found another channel. Notable examples of this character are found near Cincinnati, in terraces which show that the Ohio and Miami rivers once flowed through entirely different channels from those now occupied.

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[2] The peat deposits of Ohio are exhaustively treated by Dachnowski in Bulletin 16 of the Geological Survey of Ohio.

[3] The Muskingum soils closely resemble the Dekalb, a series covering large areas in western Pennsylvania, West Virginia and Kentucky.

These terrace soils have been included in the *Fox* series when composed chiefly of limestone detritus and in the *Chenango* series when derived from sandstones and shales.

Below the terraces lie the modern alluvial or first-bottom lands, which are still in course of formation. Examples of the great changes which a single flood may accomplish were shown in the Miami bottoms in the flood of March, 1913, in which large areas were covered from a few inches to several feet with gravel.

Such deposits of gravel have occurred throughout the formation of terrace and bottom soils. When their surfaces become converted into soil, through the processes of weathering and the deposit of silt from the highlands, they possess the combination of superior fertility and natural drainage which makes them very valuable.

The erratic caprices of the rivers in piling gravel and sand in one place and silt and clay in another have caused the subsoils of some of the terraces and bottoms to be so infiltrated with clay as to make artificial drainage necessary.

Many minor divisions in the soil formation of the State have been caused by the overlapping of the general agencies above noted and are being studied and mapped by the Experiment Station, acting in cooperation with the Bureau of

Soils of the United States Department of Agriculture and the College of Agriculture of the State University.

The general agencies which have operated in the formation of the soils of Ohio have also been at work in other states and the state experiment stations generally are engaged in the surveying and mapping of the soils of their respective states.

SOILS OF THE OHIO EXPERIMENT FARMS

The Northeastern Test Farm, at Strongsville, is in southern Cuyahoga county. Its soil is classed as Trumbull silty clay loam, and lies over an impervious, gray shale from which it has been derived with but slight modifications by glaciation, and which has given its color to the soil. The shale comes to the surface in places in low ridges, in which the rock is crumpled as by lateral pressure. The level topography and the color and markings of the surface shale suggest that it has been deposited as a mud in shallow water at a comparatively recent period, as measured in geologic time. The subsoil and underlying shale are so impervious to water that underdrainage is indispensable to profitable cultivation. The original forest growth was chiefly the shallow-rooting beech and elm, with sugar maple on the better drained areas. Until drained, this soil is wet, cold and of very low productiveness, and cultivation had been abandoned and the land used for pasture for many years before it was put under experiment.

The Trumbull County Experiment Farm, near Cortland, about 55 miles east of Strongsville, is almost a duplicate of the Strongsville farm in topography and soil, although its drainage is a little better and it more nearly represents the average soil of the Western Reserve.

As we go southward in this quarter of Ohio the gray, clayey shale dips under the more sandy, yellowish shales of the Waverly series, and after the watershed is passed the topography is more rolling, giving better drainage.

The *Central farms* of the State Experiment Station, at Wooster, lie on a gently sloping plateau, about 200 feet above the nearby creek valleys, and their principal soil, the Wooster silt loam, is more yellowish in color, more easily worked, less impervious to water and warmer than the more northerly soils. The sandy shale lying over stratified sandstone, which lies 3 to 6 feet below the surface, gave natural drainage until the plow sole and the trampling of teams had obliterated the vertical drainage channels left by the decaying roots of the whiteoaks which, with an occasional chestnut and an undergrowth of dogwood, constituted the major part of the native forest growth. It is still possible to drain buildings and fields by digging down into this sandrock. For three-quarters of a century before being taken over by the Experiment Station, in 1892, this group of farms had been under the thoroughgoing husbandry of the Pennsylvania German farmers by whom this region was settled, and the buildings they had erected bear witness to the responsiveness of the soil.

The Mahoning County Experiment Farm, at Canfield, is about 20 miles south of the Trumbull County Experiment Farm. Its soil, the Canfield silt loam, more nearly approaches the Wooster soil in character than that at Cortland, the difference being chiefly in a greater need of drainage on the Mahoning than on the Wooster farm. In fact, the same name, Canfield silt loam, has been given to the less well drained parts of the Wooster land.

These three farms fairly represent the glaciated region of eastern Ohio. In the non-glaciated area are three farms, located in Meigs, Washington and Belmont counties.

The Southeastern Test Farm, at Carpenter, Meigs County, was taken over as an experiment farm in 1904 for the purpose of studying the agricultural conditions of the hilly counties of southeastern Ohio. The fertility experiments on this farm are located on a Muskingum silt loam, formed from the decomposition of sandstones of the barren coal measures. The soil contains more clay than that at Wooster, but in color it more nearly resembles the Wooster than the Strongsville soil.

The Washington County Experiment Farm is in two divisions: The one devoted to field crops, at Fleming, is on a Muskingum soil quite similar in character to that at

Carpenter, while the truck farm, near Marietta, is on the gravelly alluvium of the flood plain of the Muskingum River.

The Belmont County Experiment Farm is on the National Road, four miles west of St. Clairsville. The fertility experiments here also are located on a Muskingum soil, as that formation represents a larger area in the county than any other.

In the hilly counties of the State it is very difficult to find on any farm an area sufficiently large to permit the laying out of an extensive field experiment, and the attempt has been made to overcome this difficulty by so planning the work on these three farms that, while certain parts will articulate for purposes of comparison, each farm will take up some problem different from those of the other two.

Eight experiment farms have been operated in the western half of Ohio for periods of seven years or longer; two in the area covered by ancient Lake Maumee, four on the glaciated limestone soils of mid-western Ohio, and one each on the old Illinoian glaciation and on the borderland between that and the Wisconsin ice-period.

In 1894 a small tract was leased on one of the sandy beaches of the ancient lake, near Neapolis, Fulton County. The land was then covered with a native forest of small white and black oaks, which was cleared away and a 3-year rotation of potatoes, wheat and clover was begun. It soon became evident that this soil requires mechanical as well as chemical treatment. When kept so constantly under the plow as in this short rotation the small proportion of fibrous matter was soon exhausted and the fields became dunes of wind-blown sand. Where the soil of neighboring farms had been kept in grass and compacted by the hoofs of pasturing livestock it gradually improved in texture and it was possible occasionally to grow a good crop of corn or potatoes, after which it was necessary to return it to grass again. The test was abandoned after 7 years cropping, because of inability to secure a satisfactory tenure of the land.

The Southwestern Test Farm is located at Germantown, southern Montgomery County, and was established in 1904 in cooperation with an association of tobacco growers. The soil of this farm represents the silt loam phase of the

Miami series. The land lies some 300 feet above the level of the Great Miami River and is underlaid at a few feet with the gravel and sand of the glacial drift.

In 1909 the Commissioners of Hancock County leased to the State Experiment Station a tract of 20 acres adjoining the corporate limits of Findlay and formerly used as a part of the county fair ground. The limestone is covered with but a few inches of soil on part of the tract, and with but a few feet on any of it, and it was taken over as representing almost a pure limestone soil, but the previous use of the land had resulted in irregularities in yield which made the results less dependable than is desirable and the work was discontinued in 1922.

The Paulding County Experiment Farm is located on a tract representative of the soil deposited during the latest stages of Lake Maumee. The soil of this farm is a dark brown to black, stiff clay, cracking open when very dry and forming almost unbreakable clods if worked when either too wet or too dry. It is classed as *Fulton clay.* It is extremely rich in all the elements of fertility, and when properly handled produces such large crops, especially of corn, that at the time the experiment farm was established the highest priced agricultural lands in the State were found in this county. The original timber was elm and other semi-aquatic growths, and the land was incapable of cultivation until the water level had been lowered by great open ditches and systematic underdrainage.

The Miami County Experiment Farm is located a mile and a half west of Troy, on a tract representative of the combination of yellow and black soils of the Miami series common over western Ohio and parts of Indiana. On this farm the yellow soils are the lighter colored phase called *Crosby silt loam* and the dark soils are classed as *Brookston,* these names simply indicating small variations from the more yellow Miami silt loam and the darker and more widely distributed Clyde soils. The experiment plots on this farm are so laid out as to include both kinds of soil.

The Madison County Experiment Farm is located about four miles west of London, having been left to the county for this purpose by the will of Miss Adah Bertha

Coover. The soil of the part of this farm used in fertility tests is classed as *Miami silty clay loam.*

The Clermont County Experiment Farm is located on a soil typical of the "white clay" that covers a large area in Clermont and adjoining counties. It lies south of the limit of the last or "Wisconsin" glaciation, but within the area covered by the older "Illinoian" ice period. The soil under experiment has been classed as *Clermont silt loam.* When first cleared from the forest, early in the Nineteenth Century, it was fairly productive, as shown by the character of the old farm buildings; but the natural drains formed by the decaying tree roots had long since become obliterated and the land had become sodden and cold and was producing only the most meager crops.

Although the limestone, lying within a few feet of the surface, had contributed to the original formation of this soil, its very long exposure has resulted in so complete a leaching out of the lime that liming is producing almost as great an effect here as on the soils of sandstone origin in the eastern half of the State.

The Hamilton County Experiment Farm is located near the northern boundary of the county and on the borderland between the earlier and later ice periods. Its soil is classed as *Cincinnati silt loam.*

Both the Clermont and the Cincinnati soils have been modified by loessal deposits, made during the long ages between the earlier and later glaciations. Similar soils are found throughout southern Indiana and Illinois, indicating that there may have been a period when desert conditions prevailed over this region and the wind became an active factor in soil transportation.

III

An Outline of Farm Chemistry

The science of chemistry—Science is knowledge arranged in orderly form. A science is a group of related facts, so arranged as to exhibit their relations to each other. Chemistry is the branch of science which deals with the composition and transformation of matter, and the chemistry of the farm, or agricultural chemistry, is that division of chemistry which explains the composition of soils, plants and animals. A general knowledge of this division of chemistry is therefore indispensable to the most intelligent management of the farm.

Chemical elements—A chemical element is a substance which cannot be separated into two or more substances of different character, such as oxygen, iron, and sulphur. Nearly 100 elements are now known, but of these only fifteen are usually found in agricultural plants, and five of these fifteen are probably not essential to the life of the plant.

Essential elements—The essential elements are oxygen, nitrogen, hydrogen, carbon, phosphorus, calcium, magnesium, potassium, iron and sulphur, and the five elements of less importance are silicon, aluminum, chlorine, manganese and sodium.

Accidental elements—In addition to these fifteen elements, a few other elementary subtances are sometimes found in plants. Iodine, for example, was first discovered as a constituent of the ash of certain sea weeds. Copper and zinc have been found in plants growing near mines, or near manufacturing works where salts of these metals are employed. Arsenic, lithium, rubidium and titanium have also sometimes been found in the ash of plants, but not in sufficient quantity to have any economic importance.

Elementary forms—None of the essential elements of plants except iron and sulphur are ever found in the free state. They are either mixed together, as oxygen and nitrogen in the atmosphere, or are chemically combined with oxygen, or with that and other elements.

Chemical combination—It is important to understand the difference between a simple mixture and a chemical combination. The air we breathe is a mixture, consisting chiefly of two elementary gases, oxygen and nitrogen. Oxygen, in its pure state, would act so energetically upon the tissues as soon to destroy them, and the function of nitrogen is to dilute the oxygen so that we can breathe it, just as we dilute lemon juice with water to make it drinkable, the oxygen still retaining its original properties, but in a modified form. In chemical combination, however, the properties of the original elements are completely changed. Thus water is a chemical combination of two very dissimilar gases, oxygen and hydrogen, the two gases being combined in the proportion of two parts by volume of hydrogen to one of oxygen. In nitric acid nitrogen, oxygen and hydrogen are combined, thus forming one of the most corrosive acids out of the constituents of air and water.

Combining weights—Another distinction between mixture and combination lies in the fact that, while two substances may be mixed in any proportion, the elements combine with each other only in certain definite quantities. In the case of water, for example, two volumes of hydrogen are combined with one volume of oxygen. Hydrogen, however, weighs only one-sixteenth as much as oxygen, so that the actual weights of the hydrogen and oxygen in water are as one to eight. Hydrogen and oxygen may be combined in another fluid, known as peroxide of hydrogen, a substance entirely different from water in its properties, as it corrodes the skin and bleaches vegetable colors. Chemists have not been able to produce this substance by the direct union of oxygen and hydrogen, but by complex methods it is possible to cause water to take up another measure of oxygen. It is therefore assumed that peroxide of hydrogen is made up of two volumes each of hydrogen and oxygen, or 2 parts by weight of hydrogen to 32 of oxygen.

There are other elements, however, with which hydrogen is found to be combined in half the proportion in which it combines with oxygen in water, and there are compounds containing oxygen in which one of the volumes of hydrogen is replaced by a volume of some other element.

The atom—Because of these facts chemists have assumed that every substance, solid, liquid or gas, is made up of separate, undivided particles, just as the sea beach is made up of individual grains of sand; these imaginary elementary particles—for no microscope has yet been constructed of sufficient power to enable us to distinguish them from each other—are called atoms, and these atoms are believed to be governed by laws of combination under which they invariably unite with each other in multiples of certain weights. These weights are known as combining weights, or atomic weights.

The molecule—As an atom is the smallest particle of an element, so a molecule is the smallest particle of a compound. For example, two atoms of hydrogen combined with one atom of oxygen constitute a molecule of water.

Chemical symbols and formulas—For convenience in statement each element is given a symbol, which is usually the first letter, or an abbreviation, of its English or Latin name, such as O for oxygen, N for nitrogen, Na for sodium (the Latin name of which is natrium), S for sulphur, etc. In a chemical formula, small numerals to the right of the symbols indicate the relative weights in the compounds of the elements composing it. Thus the formula H_2O shows that two atoms of hydrogen are united with one atom of oxygen and that the weights of the hydrogen to the oxygen are as 2 to 16.

Atomic weights—The symbols and atomic weights of the elements generally found in plants are given below, taking hydrogen as unity:

ELEMENT	*Symbol*	*Atomic weight*
Aluminum	Al	27.1
Calcium	Ca	40.1
Carbon	C	12.0
Chlorine	Cl	35.5
Hydrogen	H	1.0
Iron (Ferrum)	Fe	55.9

ELEMENT	*Symbol*	*Atomic weight*
Magnesium	Mg	24.3
Manganese	Mn	54.9
Nitrogen	N	14.0
Oxygen	O	16.0
Phosphorus	P	31.0
Potassium (Kalium)	K	39.1
Silicon	Si	28.3
Sodium (Natrium)	Na	23.0
Sulphur	S	32.1

Oxygen is a colorless gas, and constitutes about one-fifth of the earth's atmosphere, in which it is mixed with about four times its volume of nitrogen, together with a small quantity of other gases. Oxygen is combined with most of the elements composing the earth's crust, of which it constitutes nearly half the total weight, and it comprises more than one-third of the weight of plants and animals. It is therefore the most abundant substance in nature.

Pure oxygen is a tasteless, odorless gas, which combines with most other substances, sometimes with great energy. If a splinter of wood be set on fire and then the flame be extinguished leaving a red coal at the end, and this be inserted in a jar of oxygen gas, it will immediately burst into flame. If a red-hot iron wire be placed in pure oxygen gas it will burn with great brilliancy.

Burning is in fact a chemical combination of oxygen with the carbon of the wood or the iron of the wire; a combination which takes place so energetically as to produce heat and flame. When wood is burnt the product is carbon dioxide (CO_2) a gas which passes off into the atmosphere, and when iron is burnt the product is an oxide of iron. In the presence of moisture oxygen attacks iron and many other substances at ordinary temperatures, a process which is known as oxidation. The rusting of iron is a very familiar illustration of this process.

Nitrogen, like oxygen, is a gas in its free state, and constitutes about four-fifths of the atmosphere, where its chief function appears to be to dilute the oxygen, as otherwise the action of the latter would be so energetic as to destroy life instead of supporting it. In combination with other elements, nitrogen is found in every living organism, whether plant or animal, and it is found in the soil as a constituent of plant and animal remains.

Nitrogen does not support combustion or respiration. If a lighted candle be placed in a jar of pure nitrogen it will be at once extinguished, and if an animal be confined in pure nitrogen it will soon perish, not because nitrogen is poisonous, for if it were we could not breathe it as we do in the air, but because it performs none of the functions of oxygen.

Nitrogen is an essential constituent of every living cell, and yet the limitless supply of nitrogen in the atmosphere is wholly unavailable to the higher animals and to the plants we cultivate until it has first been combined with some other element, and so far as is now known this combination is effected in nature by two agencies only: electricity, and the growth of certain extremely minute organisms whose home is in the soil. Of these agencies, the latter is by far the most important, as investigation has shown that the amount of electrically combined nitrogen which reaches the earth annually is but a few pounds per acre.

Hydrogen is also a gas, but it does not occur as such under ordinary conditions. Combined with other elements it is found in natural gas, illuminating gas and sewer gas. One-ninth the weight of water is hydrogen, hence water is the great storehouse of this element. Hydrogen is the lightest of the elements, a volume of hydrogen weighing only one-sixteenth as much as an equal volume of oxygen and only one-fourteenth as much as one of nitrogen. It is due to this fact that hydrogen is used for the inflation of balloons. Hydrogen does not support combustion like oxygen, as a lighted candle will be extinguished if passed into an inverted jar of hydrogen, but it will set fire to the hydrogen, which will burn with a bluish flame. If the jar of burning hydrogen be turned mouth upward the gas will escape in a sheet of flame. When mixed with air hydrogen becomes dangerously explosive, hence the destruction which sometimes follows the escape of gases containing hydrogen.

Carbon is found in the familiar forms of coal, lampblack and blacklead, and also in the diamond, all of which substances, when exposed to intense heat in the presence of oxygen, combine with that element in the form of the gas known as carbon dioxide, the "carbonic acid gas" of the earlier chemists. Carbon, oxygen and hydrogen, in various combinations, form the fibers, sugars, starches, and fats—the group of plant constituents known as carbohydrates—and with the further addition of nitrogen the proteid bodies are formed.

As coal is burned in the furnace or under the boiler to produce heat and power, so the carbohydrates of the food are the fuel by which the body of the animal is kept warm and its energy is maintained.

Phosphorus is never found in nature except in combination with oxygen and other elements. When separated by the chemist from these combinations it is known in two forms, (1) a yellowish, translucent, wax-like body, so highly inflammable that it will take fire by moderate friction—hence its use in friction matches; and (2) a brick-red, opaque substance, much less inflammable. The yellow form is very poisonous; the red form is not.

Phosphorus is one of the chief constituents of animal bone, of which it forms about ten percent, being combined with lime in the substance known as phosphate of lime.

Immense deposits of phosphatic limestone are found in South Carolina, Florida, Tennessee, and near the junction of Wyoming, Idaho and Utah. Phosphorus is also found in combination with calcium in the mineral apatite, which occurs both in crystals and in masses and is widely distributed.

Calcium is the distinguishing element in limestone, but its affinity for oxygen is so great that it is never found in the pure state. When separated from its combination it is found to be a brilliant, ductile metal of a light yellow color, which immediately combines with oxygen on exposure to the air and is converted into lime, or calcium oxide. On further exposure to air the lime absorbs carbon dioxide from the atmosphere and becomes carbonate of lime, a compound of the same constitution as limestone.

Magnesium is practically always associated with calcium in limestone. In marble and the purer limestones the quantity of magnesium may be small, but in many limestones the proportion of magnesium may amount to two-thirds that of the calcium—more or less. Such magnesian limestones are known as dolomites.

Iron is found in practically all soils in the form of iron rust, which is a combination of iron with oxygen. It is not unusual for a soil to contain 20 tons of iron per acre in the upper 7 inches, and it may contain much more than this quantity. It is estimated that iron composes 5 percent of the earth's crust.

Although so abundant in the soil, iron constitutes but a very small part of the tissues of the plant or animal, and yet this small part is of vital importance. Deprived of iron, plants lose their green color and growth ceases, and the blood of animals becomes pale and ceases to perform its function.

Sulphur is found uncombined in volcanic regions and in a few natural deposits, one of the most remarkable being in Calcasieu Parish, Louisiana. A compound of sulphur and lime, known as gypsum, is found in extensive natural deposits, and a compound of sulphur with iron, known as iron pyrites, is found, not only in large deposits but in widely scattered fragments which are sometimes mistaken for gold ore because of the bright yellow color of the compound.

Silicon is the second in quantity of the constituents of the earth's crust, oxygen being the first. Like most of the elements silicon is not found in the free state, but in combination with oxygen, as silica or quartz. It is found chiefly in the stem and leaves of plants, and it was at one time supposed that it gave stiffness to the straw of grain, but this has been shown not to be true. While it is usually found in plants, it does not seem to be necessary to their growth.

Aluminum is a constituent of clay, and while it is usually found in plants it is not necessary to their growth, except as its compounds may be useful in holding the necessary elements in storage.

Chlorine and sodium are the constituents of common salt, of which chlorine composes about three-fifths and sodium two-fifths. In its free state, at ordinary temperature, chlorine is a greenish-yellow gas, much heavier than air, and intensely suffocating. Were the chlorine in sea water set free it would occupy five times the space now filled by the ocean. Sodium is a lustrous, wax-like substance, resembling silver in appearance, so light that it will float on water, and with such an affinity for oxygen that on exposure to the air it at once becomes tarnished, and when placed in contact with warm water it combines with the oxygen of the water with such energy as to set the hydrogen on fire.

Manganese is found in combination with oxygen in many iron ores and other minerals and rocks. It is a grayish white metal, hard and brittle, and is used but little except that a small proportion of it is present in some kinds of steel.

Acids, bases, and salts—When oxygen and hydrogen enter into combination with nitrogen, phosphorus, sulphur, carbon, chlorine or silicon, in the absence of other elements, the resultant compound, which is usually a liquid or a gas at ordinary temperatures, has a sour taste and sometimes a very corrosive action. Such compounds are called acids.

When, however, the combination is between oxygen and hydrogen on the one hand and iron, aluminum, potassium, sodium, calcium, magnesium or manganese, on the other, the product is a solid, and is alkaline in character, sometimes so strongly so, as in the case of potassium, sodium and calcium, as to be caustic in action, even to the extent of destroying the tissues of plants and animals. Caustic potash, caustic soda and lime are familiar alkalies.

Acids and alkalies combine with each other readily, and sometimes with great energy, producing substances which are entirely different in their properties from either of their constituents. The most familiar combination of this character is that of sodium with chlorine known as sodium chloride, or common salt, and hence similar combinations are called salts. The reaction by which such salts are formed may be represented by the equation:

$$\begin{gathered}2\ HCl\ \text{(Hydrochloric acid)} + Na_2O\ \text{(Sodium oxide)}\\ = 2\ Na\ Cl\ \text{(Sodium chloride)} + H_2O\ \text{(Water)}.\end{gathered}$$

In such a reaction both original compounds are broken up, the acid element and the alkaline, or basic element, as it is more properly termed, unite and the hydrogen and oxygen go off as water.

Some familiar salts—Iron rust is a combination of iron with oxygen, or with both oxygen and hydrogen, and from these combinations most of the iron used in the world's industries is extracted. Iron is sometimes found in combination with carbon, and a compound of iron with oxygen and sulphur, known as pyrites, is of vast importance in the manufacture of sulphuric acid. This substance is also called "fool's gold," because its glistening, yellow particles often deceive the uninformed. It is easily identified by its light weight and by the fact that it turns black when heated. Calcium and magnesium are combined with carbon and oxygen in limestone and marble. Calcium is also combined with sulphur and oxygen in gypsum, the rock from which plaster of Paris is made by burning, and with phosphorus in the phosphatic rock found in South Carolina, Florida, Tennessee and other regions. Potassium is found combined with chlorine and with sulphur in natural deposits of kainit, potassium chloride, or muriate of potash, and potassium sulphate, found near Stassfurt, Germany, and in Alsace, France, while sodium is not only found in combination with chlorine as common salt, but immense deposits of the combination of sodium with oxygen and nitrogen, known as sodium nitrate, nitrate of soda, or Chile saltpeter, are found in Chile, South America.

While the basic elements are frequently associated with each other in these combinations, this association is rather that of a mixture than of a chemical combination, the bond which unites them being, not their affinity for each other, but their common affinity for the element or elements belonging to the acid group. Thus there may be any percentage of calcium or magnesium in limestone, but there is always 48 pounds of oxygen and 12 pounds of carbon for every 40 pounds of calcium, and the same quantity of oxygen and carbon for every 24 pounds of magnesium.[1]

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[1] See "Everyday Chemistry," by Alfred Vivian, for a more complete discussion.

IV

Soil Organisms and Their Function

The first life—If we mix with the rock dust, described in the first chapter, a little soil and expose it for a few months to summer weather, placing it in a partially shaded place, but where rain may fall upon it, there will probably appear on the surface after a few weeks a greenish coating. If we examine this green substance carefully under the microscope we shall find it to consist of extremely small, single-celled plants—algeae, they are called by the botanist. Further examination of the deeper layers of the soil, employing the methods of microscopic research practiced by the bacteriologist, will show that these layers also are inhabited by similar organisms, but which are colorless and are able to grow in the absence of light. In fact, the bacteriologist has shown that,

> ". . . the sluggish clod, which the rude swain
> Turns with his share and treads upon . . ."

of which Bryant wrote, is in fact the dwelling place of countless myriads of living organisms, whose function is the transformation of the inert minerals of the rocks into combinations adapted to the nourishment of the plants we cultivate, and through them, of ourselves.

Nitrogen fixation—Probably the first living organisms to inhabit the earth were able to live in darkness and to combine the crude elementary substances dissolved from the rocks with the nitrogen of the air circulating in the upper layers of the powder to which the surface of the primeval rocks had been ground by frost and sun, wind and rain, ice and flood. Such organisms are at work today. They are attached by millions to the soil particles, from which they draw the mineral elements required for their growth, just as the lichen obtains its minerals from the face of the rock to which it is attached, while they take from the air and water circulating in the soil the oxygen, nitrogen and hydrogen, and sometimes the carbon, necessary to complete their tissues. These elements they combine into the protoplasm with which every living cell is filled. When their term of existence, whatever it may be, is completed they leave a substance in which the elementary bodies have entered into the first stages of combination essential to their service in the nutrition of the higher organisms.

This appears to be the initial stage of bacterial action—the first step in the multitude of transformations through which the elements must pass before they are finally combined in the support of that highest form of earthly existence, the "living soul" of man.

It is probable that such organisms inhabited the sands for ages before there was sufficient accumulation of combined plant food to support the growth of higher plants, for much of the product of their work must have been washed out and carried to the sea by the torrential rains and floods which geology shows to have prevailed in primeval times. But at length the higher plants obtained a foothold; vegetation began to grow upon the earth, and each annual growth, as it was returned to the soil, added to an accumulation of vegetable material which served as a storehouse for plant food that, having once been brought into available combination, was in condition to be used over and over again in the growth of succeeding generations of plants.

Eremacausis—Under natural conditions the annual growth of vegetation—grasses in the prairie and leaves in the forest—falls to the ground and there becomes occupied by species of bacteria which consume its substance, combining its carbon with atmospheric oxygen with the evolution of carbon dioxide; a process analogous to the respiration of animals, by which the oxygen of the air is combined with carbon digested from the food and carried in the blood to the lungs, from which it is exhaled as carbon dioxide; or which may be compared to the burning of coal, a chemical process in which the carbon of the coal is combined with the oxygen of the air and passes off as carbon dioxide. Because of its similarity to that of burning this process is called eremacausis, the meaning of which is slow burning.

In open, sandy soils and under conditions of moderate moisture this process may consume practically all the vegetable tissue, leaving only the ash to be added to the soil. Such conditions have prevailed in the semi-arid regions, and there we find soils consisting almost wholly of sand and rock dust reinforced with the combined minerals resulting from the decay of the annual vegetation through countless ages. Because of the scanty rainfall these soils have lost comparatively little of this material through leaching, and consequently, when they are supplied with water through irrigation they are usually found to be extremely productive.

Humus—Where the rainfall is more abundant and the growth of vegetation consequently more luxuriant the process of eremacausis may be limited to the superficial layer, that below being packed so closely as to impede the circulation of air, and this becomes the food of earthworms and burrowing insects and animals, which mix it, together with their remains, with the deeper layers of sand and rock dust, where, deprived of air and under excess of water the processes of decay are retarded and there slowly accumulates a black, formless substance to which the name "humus" has been given.

Humus a storehouse of plant food—Consisting, as it does, of material which has once been organized in living tissues, humus would be expected to serve as a storehouse from which supplies might be drawn for the feeding of our crops, and experience has proved this expectation to be well founded; the presence of an abundance of humus, as indicated by the dark color of the soil, being an assurance of a fertile soil, if drainage and other physical conditions are favorable. But the decomposition of the humus and its conversion into a form suitable for the nutrition of growing plants is not a matter of mere solution in water. If it were, the humus would not accumulate in the soil, but would be carried out in the drainage. On the contrary, the greatest accumulations of humus are found in peat bogs, which are constantly saturated with water, and it is in fact this saturation which, by preventing access of air, makes possible the formation of humus.

The transformation of humus into available plant food is accomplished by the action of bacterial organisms, some species of which are able to exist in the absence of air and to obtain their oxygen from the humus itself and are called *anaërobic,* while the name *aërobic* is given to those which require air.

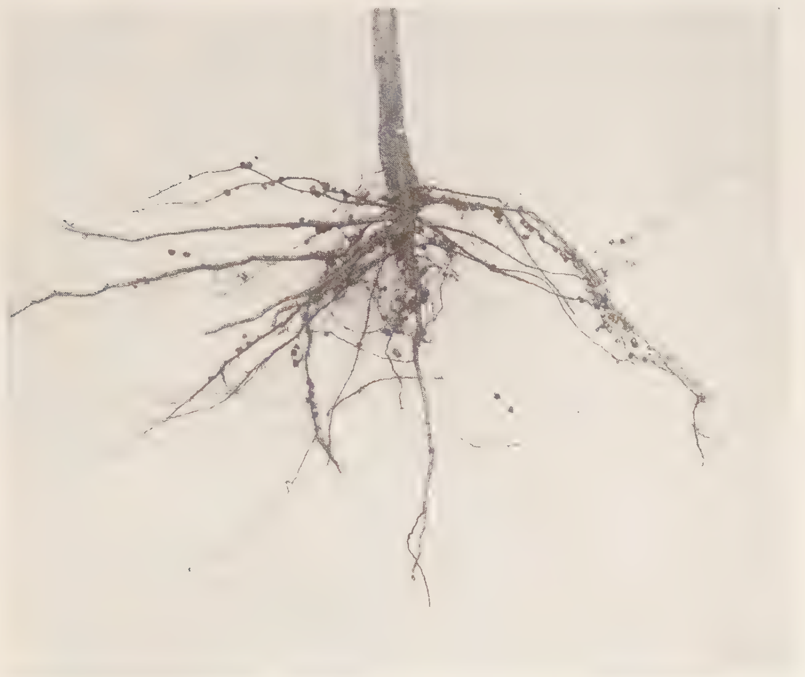

FIGURE I.—NODULES OF THE SOYBEAN

Ammonification and nitrification—The first step in this transformation is accomplished by organisms which are more or less independent of air, and whose work results in the combination of the nitrogen of the humus with the hydrogen of water in ammonia (NH_3). When the humus is fully exposed to the air by drainage and tillage certain species of aërobic bacteria take up the work and cause the substitution of oxygen for the hydrogen of the ammonia, thus converting it into nitric acid. Winogradsky and Warrington have shown that there are two steps in this operation, performed by different species of bacteria, the first resulting in the production of nitrous acid (HNO_2) in which one atom of nitrogen is combined with two atoms of oxygen, and the second adding another atom of oxygen and producing the compound HNO_3 or nitric acid.

The leguminous plants are large consumers of nitrogen and are assisted in obtaining this element by the mediation of a third group of bacterial organisms—the nodule-inhabiting bacteria of the legumes. These nodules are found on the roots of the clovers, peas, beans and other leguminous plants. They may be no larger than pinheads, or they may be as large as small peas. Usually, they are found on the upper roots, for they require air for their growth but they are attached to the roots by such fragile connections that they will be stripped off in lifting the plant unless care is exercised.

It appears that the nodule bacteria are parasitic in their first attack upon the plant; that is, they live upon the ascending sap, and hence they would be injurious, were it not for the fact that after they have completed their brief existence they leave the nodules filled with matter rich in combined nitrogen, which is ready to enter into the nutrient fluid from which the tissues of the plant are built.

Transformation of mineral elements—Nitrogen fixation is but one of many transformations of elementary substances into forms adapted to the nutrition of the plants we cultivate, which are accomplished by living organisms. Calcium and magnesium, in their elementary condition, are unavailable to our crops, but when these elements are combined with carbon and oxygen, through the agency of bacteria, corals and other low forms of life, they become the massive limestones that cover such large areas of the earth's surface and furnish the carbonate of lime which is one of the chief constituents of the skeleton.

The same general principles have governed the formation of the deposits from which our supplies of phosphates and potassium salts are drawn. Even the silica, sulphur and iron, which are constant constituents of the plant, owe their availability to similar agencies.

In fact, such organisms seem to stand at the foot of the ladder of life, from whatever viewpoint we may regard it.

There are therefore three principal groups of soil bacteria which are directly concerned in feeding the crops we cultivate, namely: (1) those which combine the free nitrogen of the air circulating in the upper layer of soil with carbon, oxygen, hydrogen and the crude mineral elements; (2) those which work over the organic residues in the soil, recombining the nitrogen of these residues with oxygen and producing ammonia and nitric acid, and (3) those inhabiting the nodules on the roots of leguminous plants, and converting free nitrogen or cruder nitrogen combinations into forms available to the host plant.

Ammonia as plant food—Plants which grow in water must use their nitrogen mostly in the form of ammonia, since the free oxygen of the atmosphere is required for the production of nitric acid, the combined oxygen in water not being available for this purpose. It is probable, also, that the hydrogen required for the production of ammonia is chiefly derived from hydrogen compounds, such as marsh gas, which are more easily decomposed than is water.

In the case of some plants a third transformation seems to be necessary before nitrogen can be utilized, namely: the conversion of nitric acid into a neutral salt. This is conspicuously the case with red clover, and is more or less true of most leguminous plants, especially those which show large proportions of lime upon analysis.

Ammonia and nitrous acid are gases, and nitric acid is a liquid. In order, therefore, that these compounds shall be retained in the soil until required by growing crops, and not escape into the air or be carried off in the drainage, it is necessary that they be converted at the moment of formation into more stable compounds.

In manure heaps ammonification takes place with such vigor that on stirring the heap the escape of ammonia gas into the atmosphere may be detected by the odor, but under the conditions ordinarily prevailing in the soil the ammonia is so quickly changed into nitrous acid and that into nitric acid that comparatively little loss occurs in these intermediate steps. For the preservation of the nitric acid, however, as well as to produce the soil conditions most favorable to the functional activity of the nitrifying bacteria, it is essential that a salifiable (salt forming) base be present, and the most effective substance for this purpose is the carbonate of calcium and magnesium which is found widely distributed over the earth in the form of limestone. Nitric acid combines with this substance forming nitrate of lime, a neutral salt.

Soil acidity—There are extensive areas, however, over which the soil has been formed from sandstones, shales and other rocks deficient in the lime elements. Such soils may be well supplied with potassium, but under ordinary soil conditions this potassium is so slowly available that the addition of a more soluble form of potassium becomes necessary.

Before the discovery of the great deposits of nitrate of soda in Chile, saltpeter (which is nitrate of potash) was manufactured in Europe by throwing mixtures of loam, manure, marl and wood ashes into shallow heaps or beds, which were sometimes kept open by racks or gratings. The material was moistened occasionally with liquor from stables or barnyards and was shoveled over at frequent intervals. After some months' treatment the earth was leached with water and the liquor evaporated, the resultant salt being a mixture of nitrate of lime and nitrate of potash.

In this process the potassium was derived from ashes, from manure and barnyard liquor, and from the humus of the loam. That is, it was potassium which had at one time composed a part of living organisms, and was therefore in a similar condition to the calcium of limestone, which is composed of the remains of shell bearing organisms. In other words, the potassium, calcium, and other minerals of the original earth crust are probably of but little value to the crops we cultivate until they have entered into the complex combinations found in living organisms, and for this reason the potassium of the particles of granitic sand in the soil is not in condition to combine with the nitric acid formed by bacterial action. In fact, chemists have for many years endeavored in vain to discover some method by which the tremendous store of potassium found in rocks and soil—a single acre of ordinary land may contain 15 to 20 tons of potassium in the upper seven inches—might be converted economically into available form.

The calcium of the soil, like the potassium, may be derived in part or altogether from fragments of the original earth-crust, in which case it also will be acted upon too slowly to serve as a conserver of nitric acid, and there may be such an accumulation of acid as to cause the soil itself to manifest an acid reaction and to retard or inhibit the work of the organisms by which the acid is produced. In order that the calcium in the soil may serve either as a direct source of food to vegetation or as a conserver of nitric acid it must be in the form of carbonate; that is, in the form of natural limestone.

Carbonate of lime is comparatively easy to dissolve—While it dissolves very slowly in water that is absolutely pure, so weak an acid as carbon dioxide exerts a material effect in bringing limestone into solution. Ordinary soil water is always impregnated with carbon dioxide, and when such water circulates through a soil, or through rocks containing carbonate of lime, it dissolves out a portion of it, which is thrown out of solution, or precipitated, when the water is heated or is exposed to the air in a fine spray. The effect of the lime carbonate is to make the water "hard," a condition very quickly revealed when soap is used with it. The incrustation formed on the inside of a teakettle in which such water has been boiled is carbonate of lime, and when water passes between strata of limestones and emerges in waterfalls the spray may precipitate its lime in the beds of marl which are sometimes found at the foot of such cascades. Such beds are found near Covington, Virginia, near Castalia and Yellow Springs, Ohio, and at numerous other places, and are estimated to contain millions of tons of marl, which has been deposited in this manner. The formation of caverns in limestone rocks is another evidence of the solvent action of carbonated water.

In view of these facts it is easy to understand that a soil formed from non-calcareous rocks and therefore originally deficient in lime carbonate may at a relatively early date become so depleted of this substance that it cannot support nitrification, and even the surface of a calcareous soil may in time be brought to this condition by drainage and tillage, as these operations not only favor nitrification but also facilitate the passage of water through the soil.

Worms play an important part in soil building. The common angleworm lives upon the plant roots and decaying vegetation in the soil. Along with its food the worm swallows particles of sand, which serve to grind its food, just as does the grit which the fowl takes into its gizzard. In this way the organic and mineral substances of the soil are more thoroughly mixed and prepared to feed our crops.

Insects, birds and all animal life contribute to this work by returning to the soil when their term of life is ended.[1]

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[1] For a more complete discussion of the functions of soil bacteria the reader is referred to "Bacteria in Relation to Country Life," by Jacob G. Lipman.

V

The Composition of the Plant

The larger part of the growing plant is water, as may be easily demonstrated by drying a stalk of corn or a handful of grass. If such a sample be carefully dried at ordinary temperature for a few hours and weighed at intervals until the weight becomes constant it will be found to have lost from two-thirds to three-fourths of its original weight. What it has thus lost has been simply water, which has been evaporated from its tissues. The quantity of water thus lost is no greater than would have been transpired by the foliage, had the plant been left standing in the field; probably not so great, as the sunshine and wind are constantly evaporating the water from the leaf surfaces, while the osmotic processes are absorbing it at the root tips and sending it upward through the stem to replace that removed by evaporation. The cutting of the stem simply cuts off this source of supply, and consequently the tissues lose their turgidity and become dry.

In humid climates the water supply of farm crops is determined by the rainfall, and by such methods of cropping, drainage and tillage as are practised by the farmer. In arid climates the deficient rainfall is supplemented by irrigation. The water supply will be discussed more fully in the chapter on drainage, irrigation and tillage.

Dry substance—The plant does not lose all its moisture by drying in the open air, for the atmosphere constantly contains some moisture. If, therefore, the sample be placed in an oven and subjected for some time to the temperature of boiling water its weight will be further reduced by from 10 to 20 percent. This reduction is due to the loss of the hygroscopic moisture of the plant, that is, of the moisture not discernable by the unaided senses. The final drying gives us what is termed the actual dry substance of the plant.

Carbon—If the air-dry plant be placed in an iron retort from which air is excluded, but so arranged that the gases of combustion may escape, and the temperature be maintained for some time at a point somewhat above that at which bread is baked, there will be left a black substance, having the form of the original material, but less than half its weight. This black substance, known as charcoal, is composed of carbon, together with the mineral constituents of the plant; the nitrogen and hydrogen, together with a small part of the carbon having gone off in the escaping gases.

Carbon, combined with oxygen and hydrogen, constitutes the cellular tissue which forms the framework of the plant, the starches, sugars and fats and, with the addition of nitrogen and sulphur, the proteid compounds. As measured by total quantity carbon stands next to oxygen in importance in the composition of the plant.

The source of the carbon of vegetation is the carbon dioxide of the atmosphere, which is absorbed by the foliage and combined within the plant with the nitrogen and mineral elements derived from the soil and carried in the upward-flowing stream of water.

While some carbon may be found in the soil water, or may be absorbed by the plant roots from carbon dioxide produced by the decay of carbonaceous matter in the soil, practical experience has shown that the growth of crops is conditioned, not upon the carbon which such decay may liberate, but upon the nitrogen and mineral elements which are set free at the same time.

Ash—If charcoal be heated to the burning point, with access of air, its carbon will combine with the oxygen of the air and will pass off as carbon dioxide, an invisible gas, and there will be left a small quantity of gray ash, constituting usually not more than about two percent of the original green weight of the plant.

This ash contains a number of mineral or earthy substances, at least six of which are essential to the life of the plant. These six are phosphorus, potassium, calcium, magnesium, sulphur and iron. In addition to these, sodium, chlorine, manganese, aluminum and silicon are frequently present in land plants, and iodine and bromine are found in certain seaweeds.

Oxides—These minerals are found in the ash, not in their metallic or elementary condition, but combined with oxygen. For example, the calcium in the plant will be found in the ash as calcium oxide, or lime, just as burning limestone, which is carbonate of lime, in the lime kiln, results in the production of common lime, which is calcium oxide—a compound represented by the symbol CaO, and therefore composed of 40 parts by weight of calcium combined with 16 parts of oxygen.

Similarly the phosphorus of the plant will be found in the ash, not as the wax-like mineral which it is in its pure condition, but as a compound of that mineral with oxygen; for pure phosphorus cannot be exposed to the air without at once combining with oxygen, either slowly, with the emission of a whitish smoke, or with explosive violence, when subjected to friction, a property which has been utilized in the common match. This combination of phosphorus with oxygen is known as phosphoric acid, or phosphorus pentoxide, having the formula P_2O_5, and containing 62 parts by weight of phosphorus to 80 parts of oxygen, or nearly 44 percent of phosphorus and a little more than 56 percent of oxygen.

Potassium, in its pure state, is a brilliant white metal, soft enough at ordinary temperature to be cut with a knife, but combining instantly with oxygen on exposure to the air. It will float upon water, where it takes fire and burns with a purple flame. In this respect potassium differs from phosphorus, as the latter may be kept under water. To preserve potassium it is kept under petroleum, which is composed of carbon and hydrogen only. The combination of potassium with oxygen is caustic potash, known simply as potash, having the symbol K_2O, and containing 78 parts by weight of potassium to 16 parts of oxygen, or 83 percent potassium and 17 percent oxygen.

Because of the fact that the mineral elements are always found in the ash as oxides the earlier chemists reported them only as oxides in their analyses of plants and soils, and from this naturally followed the custom of considering them only as oxides in the composition of fertilizing materials; that is, as phosphoric acid and potash, instead of phosphorus and potassium.

In consonance with this practice the custom became established, especially in the fertilizer trade, of speaking of nitrogen as ammonia. These terms are objectionable because it is the nitrogen and not the hydrogen which is the essential constituent of fertilizer ammonia, nor do any plants contain ammonia in their tissues, and because, in the case of the mineral elements, it is the mineral element, and not the oxygen combined with it, which is the necessary constituent of the plant's food, and it is certain that it is not always necessary that this plant food should be presented to the plant in the oxide form.

The salt known commercially as muriate of potash, for example, is a combination of potassium and chlorine, and contains no oxygen and therefore no potash, and yet this salt is one of the most effective carriers of potassium to vegetation. Its proper name is potassium chloride.

A further objection to this practice is that the term "phosphoric acid" is confused by farmers, who are generally unacquainted with chemical terminology, with "acid phosphate" the name of the fertilizing material produced by treating crude phosphate rock with sulphuric acid.[1]

Ash elements unequally distributed—While all the essential ash elements are represented in every cell of the plant they are not uniformly distributed throughout the plant; the larger part of the phosphorus being found in the seeds and the larger part of the potassium and calcium in the stem and leaves. The average percentage of these elements in the principal farm crops is given in Table I.

Electrical transformation of nitrogen—A small amount of nitrogen is combined with oxygen by electrical agencies and is brought to the earth in rainfall, the quantity being estimated at about 5 pounds per acre annually in humid regions as a general average. This source of combined nitrogen, acting through the countless ages of the past, would account for many times the quantity now contained

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[1] Since 1928 the American fertilizer trade has replaced the terms "ammonia" and "acid phosphate" with "nitrogen" and "superphosphate."

TABLE I.—POUNDS OF ELEMENTS AND OXIDES IN 100 POUNDS OF FARM CROPS.[2]

CROP	*Nitrogen* *N*	*Phosphorus* *P*	*Phosphoric acid*—P_2O_5	*Potassium* *K*	*Potash* K_2O	*Calcium* *Ca*	*Magnesium* *Mg*	*Lime* CaO+MgO	*Sulphur* *S*
Corn	1.76	.24	.55	.34	.41	.02	.18	.20	.15
Corn stover	.81	.07	.15	.78	.94	.36	.14	.80	.17
Corn cobs	.50	.03	.06	.64	.77	.06	.01	.10	.03
Wheat	1.97	.35	.80	.35	.43	.03	.22	.28	.21
Wheat straw	.53	.09	.21	.83	1.00	.19	.10	.49	.16
Oats	2.01	.41	.94	.58	.70	.08	.11	.30	.20
Oat straw	.58	.09	.20	1.09	1.32	.36	.14	.73	.19
Soybeans	5.43	.63	1.43	1.87	2.25	.19	.38	.66	.40
Soybean straw	2.00	.07	.16	.68	.82	1.04	.59	2.43	.20
Potatoes	.35	.07	.15	.42	.55	.02	.03	.08	.03
Potato tops	.60	.07	.15	.37	.45	.45	.20	.96	.07
Red clover hay	2.17	.18	.42	1.12	1.35	1.43	.39	2.65	.19
Alfalfa hay	2.72	.29	.66	1.66	2.00	1.51	.59	3.10	.30
Soybean hay	2.56	.30	.68	1.90	2.33	1.22	1.03	3.42	.25
Timothy hay	.84	13	.30	1.34	1.61	.23	.13	.54	.16
Bluegrass hay	1.33	.24	.54	1.72	2.10	.34	.24	.87	.32

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[2] N, P and K from Bul. 247, Ohio Exp. Sta. Mg and S from Bul. 255, Ohio Exp. Sta. and unpublished data.

in the soil, were this combination as stable as that of the mineral elements; but nitrogen is constantly being liberated from the soil in the breaking down of organic tissue, and the amount now found in the upper 7 inches of ordinary soil seldom exceeds 2,000 to 3,000 pounds per acre, although it may reach ten times these quantities in mucks.

Nitrogen in crops—The rocks composing the earth crust contain traces of nitrogen, the quantity being estimated by Erdmann at nearly 5 tons per square yard of surface, taken to the depth of 8 miles,[3] but this nitrogen is less available to vegetation than is the free nitrogen of the atmosphere.

The relative proportion of grain to straw varies with different crops and with different varieties of the same crop. Seasonal and soil conditions also exert a marked influence on this point. As a general average it may be assumed that 100 pounds of straw will carry a bushel of wheat, 40 pounds will carry a bushel of oats, and 50 pounds of stover and 14 pounds of cobs will carry a bushel of corn. Of course these proportions are affected by the height at which the crop is cut.

The average yields of the various crops and the relation of these yields to each other also show considerable variations. Some regions are relatively more favorable to wheat than to corn, while in others the opposite conditions prevail. Taking the general average for Ohio, the average yields per acre for the 10 years, 1910—1919, were 36 bushels of corn, 36.5 bushels of oats, and 17.4 bushels of wheat. Such yields, with the proportion of grain to straw or stover given above, would contain per acre approximately the quantities of nitrogen, phosphorus and potassium, and of calcium and magnesium computed as lime, shown in Table II.

Table II.—Pounds per Acre of Nitrogen and Mineral Elements in Average Crops of Ohio

Crop		*Nitrogen*	*Phosphorus*	*Potassium*	*Lime*
Corn, 36.0 bu.	In grain	35.5	4.84	6.85	4.00
	In cobs	2.5	.15	3.22	.50
	In stover	14.6	1.26	14.03	14.40
	In total crop ..	52.6	6.25	24.10	18.90

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[3] Clark, "Data of Geochemistry," (Bul. 770, U. S. Geological Survey), p. 35. Note.

Crop		*Nitrogen*	*Phosphorus*	*Potassium*	*Lime*
Oats, 36.5 bu.	In grain	23.5	4.79	6.77	3.50
	In straw	9.5	1.48	17.90	12.00
	In total crop	33.0	6.27	24.67	15.50
Wheat, 17.4 bu.	In grain	20.6	3.65	3.65	2.93
	In straw	9.2	1.55	14.45	6.96
	In total crop	29.8	5.20	18.10	9.89

Experiment

A simple experiment to illustrate the importance of the ash elements may be made by growing oats in sand. The sand should be as pure quartz sand as possible. Common flower pots may be used—the 6-inch size or larger—and filled with the sand to within half an inch of the top. Leave one pot without any treatment, as a check. To one add one-twentieth of an ounce of the fertilizer known as superphosphate; to another add half this quantity of muriate of potash; to another a similar quantity of nitrate of soda; for others combine these materials in the same proportions, giving acid phosphate and muriate of potash to one pot, superphosphate and nitrate of soda to another, muriate of potash and nitrate of soda to another and all three to another. To each of the pots, including the check pot, add a few grains of sulphate of iron (Copperas) sulphate of magnesia (Epsom salt) and powdered chalk, to furnish the min-

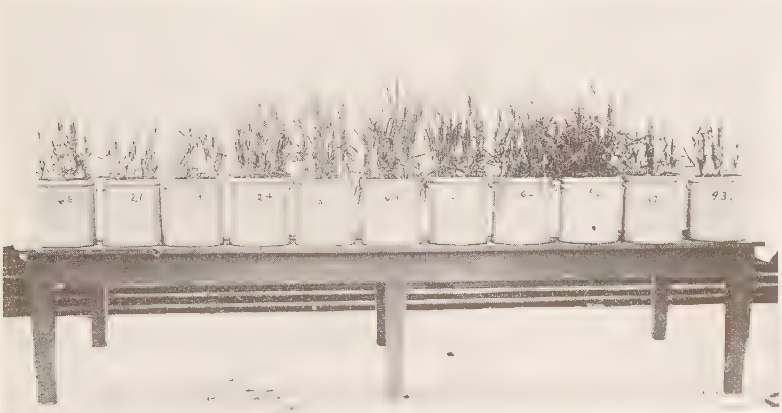

Figure II.—A POT EXPERIMENT

erals which, while quite as necessary to the plant as phosphorus and potassium, are required in relatively small quantity and are usually furnished by the soil without attention on the part of the farmer. The fertilizing materials should be sprinkled over the surface of the sand and they will be carried into the soil by the water used in watering the plants if they are kept indoors, or by the rain if left outdoors, as they may be in summer weather. In the winter they may be set near a window in a room that is kept warm. Rain water should be used in watering, and water should be given at least once each week. Coarse sand will require watering more frequently than fine sand. Six plants will be enough for a 6-inch pot, but more seeds should be planted, so as to make sure of getting six strong plants. Plant the seeds about an inch and a half deep.

The mineral elements are fundamental—Although the plant does not have a bony skeleton composed chiefly of minerals, as do animals, yet the mineral elements are as necessary to the existence of the plant as to that of the animal, and if any one of the six essential minerals be wholly withdrawn from the medium in which the plant is growing all growth will stop when the small stock of nutrients carried in the seed is exhausted.

In such an experiment as that above described it will be difficult to find a sand as free from other minerals as quartz, but the quantities of such other minerals will be so small that the effect of withdrawing any one of the essential elements will soon be manifested in the slower growth of the plant.

The non-mineral elements—The mineral elements in fact serve as nuclei, around which are gathered the compounds of carbon, oxygen, hydrogen and nitrogen composing the fiber or cellulose which constitutes the framework of the plant, and the starches, sugars, fats and proteid matters with which its cells are filled and which furnish the fuel by which the heat of the animal organism is maintained and its work performed, and the chief part of the substance out of which its tissues are constructed.

Proximate composition of crops—In considering the composition of the plant with reference to its uses in animal nutrition its elements are arranged in the five classes: Water, ash, carbohydrates, fat, and crude protein. The proportion of water varies from 7 to 15 percent in air-dry grains, hay, etc., to 70 to 85 percent in green grass, green corn, etc., and 80 to 90 percent in beets, turnips, and other root crops. The water of the plant does not of itself possess any nutritive value, but it may add to the palatability of the food and thus increase its effectiveness.

Ash—The combined ash elements usually constitute less than 2 percent of the weight of the green plant and of the grains of corn, wheat and rye; 2½ to 3½ percent of the barley and oat grain, and 4 to 8 percent of hay.

Carbohydrates—The carbohydrates include the fiber or cellulose and the starches and sugars, and are composed of carbon, oxygen and hydrogen. In the growth of the plant carbon dioxide is absorbed by the foliage, and in the mysterious laboratories of the plant it is combined with the elements of water—oxygen and hydrogen—and thus elaborated into a multitude of substances varying in character from the white starch granules of the corn or wheat grain and the sweet sap of the cane stalk, beet root, and maple tree, to the cellular tissue which contains the starch granules and the liquid sap, these variations being accomplished by slight differences in the arrangement of the elementary atoms. Thus, in starch and cellulose the atoms are believed to be grouped in multiples of the formula $C_6H_{10}O_5$; for cane sugar the formula is $C_{12}H_{22}O_{11}$; for glucose it is $C_6H_{12}O_6$. Under such a system of grouping there may be an infinite number of different combinations, all consisting of the same three elementary substances.

If pure starch or sugar be burnt it is all converted into the elementary gases from which it has been formed—carbon dioxide and hydrogen. When wood is burnt the greater part of its substance likewise passes off in the same gases, but an ash is left, consisting of the mineral elements which had been incorporated in the cellular structure of the wood.

Fat—The vegetable fats and oils are composed of the same three elements as the starches and sugars, but with a different arrangement of the molecules, the number of atoms being larger and the proportion of carbon and hydrogen greater. The composition of the common vegetable oils, olein and palmitin, is expressed by the formulae $C_{57}H_{104}O_6$ and $C_{51}H_{98}O_6$.

The temperature and energy of the animal body are maintained by the oxidation of the carbon of the food, the process being analogous to that by which the carbon of the fuel under the steam boiler is oxidized by burning. For this purpose one pound of digestible fat in the food has been found to equal 2¼ pounds of digestible carbohydrates.

Crude protein—This term is applied to a group of compounds containing nitrogen and sulphur, in addition to carbon, hydrogen and oxygen. The function of the protein of the plant is to provide the nitrogenous material which is indispensable for the growth and support of the animal organism. Crude protein constitutes 1 to 2 percent of the green weight of roots and tubers, 2 to 4 percent of that of the green corn and grass plants, 3 to 5 percent of that of green legumes, 3 to 10 percent of the hay of non-leguminous plants and 12 to 16 percent of clover and alfalfa hay. In some of the by-products of milling, such as the various oilmeals, the crude protein content reaches 35 to 45 percent.[4]

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[4] For a more complete discussion of the principles of plant growth as related to food production, see "Feeds and Feeding," by Henry & Morrison, Madison, Wis. Published by the authors.

VI

The Mechanism of Plant Growth

The nutrition process—Man and the higher animals take their food into the mouth, where it is ground by the teeth and mixed with saliva, the tongue assisting by turning it over and around; it is then swallowed into the stomach, where it is further admixed with digestive fluids, and from which, as a reservoir, it is slowly passed into the intestinal canal, where it receives still further additions of digestive fluids, and as it passes along this long canal selective organs abstract from it such portions as are adapted to the nutrition of the body and pass them into the blood, which carries them to the lungs, there to receive the purifying and life-giving influence of oxygen, and from which they are distributed to the remotest portions of the organism, the heart serving as the circulatory pump by which the nutrient stream is kept constantly in motion.

The mechanism of blood circulation is strikingly illustrated in the modern system of heating buildings by hot water. The water is heated by a furnace and was formerly distributed over the building by gravity, such distribution being made possible by the fact that when water is heated it expands and thus becomes lighter and rises, while the cooled water, becoming heavier because of the smaller space occupied, returns to the furnace. The success of such a system depends upon locating the furnace at or very near the lowest point in the circulation. But by installing a circulating pump the water may be driven steadily throughout the system whatever the relative altitude of the different portions. The heart is the circulatory pump which drives the blood throughout the animal structure, the lungs being the furnace by which the temperature is maintained through the combination of the oxygen of the air with the carbon of the food.

How the plant takes its food—But the plant possesses no mouth with teeth and tongue to comminute its food; no stomach or intestinal canal in which to store it, and no heart to drive the nutrient fluid throughout its tissues. What it does possess is a system of absorbent surfaces on the tips of its minutest rootlets—spongioles these surfaces are called—by which the nutrient solution, which has been prepared for it by the bacterial activities and chemical reactions that take place in the soil, is taken up through the process called osmosis, by which fluids and salt solutions are transmitted through membranes, and forced upward through the canals and cellular tissues of the stem to the leaves, there to meet carbon and oxygen, absorbed from the atmosphere by the foliage, and to be elaborated into the innumerable combinations which go to make up the plant as a whole.

Osmosis—To illustrate osmosis, tie a thin membrane, such as a piece of animal bladder, around the neck of a salt-mouth bottle filled with a saturated solution of salt and immerse this in a larger vessel filled with pure water. After a few hours it will be found that the water in the larger vessel has become salty, while the membrane may eventually be ruptured by the pressure from within; for in osmosis, although there is a flow from both directions, the stronger flow is toward the denser fluid.

This principle is the cause of the turgidity of the plant cells, by which the tissues are kept plump. When the water is evaporated from the foliage of the plant the concentration of the contents of the leaf cells is increased, and this starts up again the osmotic process and the cells are filled from below, the influence extending from cell to cell and from leaf through stem to root tip.

As stated above, the osmotic currents flow in both directions; the one of less concentration flowing into the cell, while one of greater concentration flows outward. In this way the compounds which have been elaborated in the leaf are carried to their respective destinations in the plant.

The intensity of osmotic pressure varies with the difference in strength of the solutions, and may become very considerable. Pfeffer, who devised an apparatus for the study of this question, reports pressures as high as 60 pounds per square inch, or sufficient to sustain a column of water 137 feet high.[1]

Capillarity also assists in the upward movement of the nutrient stream, the evaporation from the foliage causing the same upward pull that is produced in the lampwick by the flame at its end; the minute, vertical tubes with which the stems of such plants as corn or wheat or the inner bark of trees are provided furnishing the channels required for the operation of this force.

In seasons of drought, when the water supply is insufficient to meet the demands of the plant the leaves curl, thus partially closing the stomata and reducing the evaporating surface. If the drought is but temporary turgidity is restored and growth goes forward when water is given again, but if the drought continues there comes a time when the restoration of water is of no avail; for, after all, it is the vital force which governs and directs the mechanism of nutrition and growth, whether of plant or animal. It is this force which decides whether a molecule elaborated in the leaf shall be stored in leaf or flower, in stem or root.[2]

Quantity of water required for plant growth—Each leaf furnishes an evaporating surface, from which the water is constantly passing into the atmosphere. To get some idea of the area of surface thus exposed, measure the leaves of a growing corn plant when near maturity, and multiply this by the number of plants on an acre, and it will be seen that this surface may be very much greater than that of the land on which the corn is growing. Or, cut down and immediately weigh the produce of an average square yard of grass and then weigh again after a day's airing in good haying weather, and it will be found that several times as much water has been evaporated from the hay as the dry hay itself will weigh.

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[1] King. "Physics of Agriculture," p. 41.

[2] I am not unaware of the fact that it is fashionable to deny the existence of a vital force, but I am not able to account for the mysteries of plant and animal growth on any hypothesis of blind evolution and undirected energy. Unquestionably evolution has been one of the factors employed in carrying out the plans of the great Architect of the Universe, but to account for the Cosmos as we have learned to know it today either upon the theory of evolution alone or upon that of immediate creation alone is as unsatisfying to me as the pagan conception of a world resting on the shoulders of Atlas. C. E. T.

That is, from an acre of grass that will make two tons of dry hay there will pass off in drying four tons or more of water during a summer day. But this water has not been evaporated from the drying hay any more rapidly than it has been passing off from the standing grass during similar weather. It is estimated that water to the amount of 300 pounds or more passes upward through the plant and is evaporated from the foliage for every pound of actual dry substance deposited in the plant.

The dry substance—By dry substance, however, is meant not simply the small amount of nitrogen and mineral elements absorbed by the root spongioles from the soil, but the combination of these with the much larger quantity of carbon and oxygen taken into the plant by the leaves. For the function of the leaves is not limited to the evaporation of surplus water. They also share with the roots the feeding of the plant.

How the plant breathes—On the undersurface of the leaf are numerous minute, oval openings, called "stomata" (little mouths) through which carbon dioxide is absorbed. Through this source, and this alone, the plant obtains the carbon which constitutes a larger proportion of the weight of its actual dry substance than does any other element, and through this source it also obtains the major part of its oxygen, the element which stands next to carbon in the weight of its dry substance.

The living animal breathes oxygen into its lungs, combines this oxygen with the carbon of its waste tissues, which are constantly being picked up by the blood stream on its return from the extremities to the heart, the blood passing through the lungs and leaving its carbon there to be combined with oxygen and exhaled as carbon dioxide.[3]

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[3] *Experiment*

Put a teaspoonful of lime into a tumbler-full of water. Stir it occasionally for an hour or two, then let it settle, and after it has become clear pour off the clear water into another tumbler. Breathe into this clear water through a glass tube or a straw, and a white cloud will appear in the water. This white cloud is carbonate of lime, formed by the combination of the carbon dioxide of the breath with the solution of oxide of lime in the water, the carbonate of lime being less soluble than the oxide. Cold water, however, will dissolve a considerable quantity of carbonate of lime, which will be precipitated if the water is heated, as is shown by the coating which forms inside the teakettle in which hard water is heated.

Fixation of carbon—The carbon dioxide which animals exhale is inhaled by plants, and in their foliage it meets the upward flowing stream carrying the nitrogen and mineral elements obtained from the soil, and within the leaf and the growing tissues of the stem and fruit the plant fabricates out of ten or twelve elementary materials, by merely a little difference in the arrangement of their atomic structure, the bread grains upon which we subsist, the luscious fruits, the beautiful flowers, the deadliest poisons. Wonderful as are the accomplishments of the modern chemical or analytical laboratory, they do not approach in complexity of design and in perfection of result the humblest flower.

> "Behold the lilies of the field, how they grow, they toil not, neither do they spin, yet even Solomon in all his glory was not arrayed like one of these."

The foliage, therefore, performs for the plant a function analogous to that performed in the lungs and digestive organs of the animal.

The nutrient stream—But the nutrition of the plant cannot be wholly served by an upward moving stream. There must be a counter current, to carry down to the stem and roots the nutritive compounds elaborated in foliage and stem above. It is this counter current which builds the plant and stores in its various parts, whether seed or stem, leaf or root, the substances valuable for the food of animals or man, or for raiment. But whether it be current or counter current, its volume is controlled, first, by the supply of water in the soil, and second, by the supply of the mineral elements, which are dissolved in that water in such proportions to each other as to be adapted to the growth of the plant.

Obviously, since this growth is dependent upon the water stream there can be no growth without water; but pure water cannot nourish the plant; the water must carry from the soil a sufficiency of the fundamental nitrogenous and mineral substances around which is gathered the carbonaceous material absorbed from the atmosphere, or else there cannot be a sufficient expansion of leaf to maintain the evaporation which produces the upward current.

And the supply of these fundamental substances is altogether within our control. Even the water supply may be maintained by irrigation. In sufficient water and a sufficiency of available nitrogen and of a very few and easily procurable mineral substances we have the key to the maintenance of soil fertility and to the feeding of the peoples of the world. How most economically and effectively to accomplish this end is the problem before us.

VII

Drainage, Irrigation and Tillage

I.—DRAINAGE

Aquatic plants thrive only when their roots are submerged in water—Such are the seaweeds, which cover vast expanses of the ocean; the water hyacinth, which grows in such masses in Florida rivers as to obstruct navigation; the pond lilies, and many marsh grasses and other plants. The foliage of these plants extends above or floats upon the surface of the water, while the roots are suspended in the water or are anchored in the mud of the bottom.

Rice is the most important of aquatic food plants. In oriental countries the seeds are sown in seed beds which are kept saturated with water after the plants are a few inches high until they attain a height of about 6 inches, when they are transplanted to fields in which the soil has been reduced to mud and which are kept covered with water of sufficient depth to kill the weeds, until the rice crop is mature, when the water is drawn off to permit harvesting the crop. On the flat prairies of Louisiana the rice is grown with the same machinery used for the wheat crop, the seed being drilled in dry fields, which are then covered with water and kept so from the time the young plants are a few inches high until the crop is nearly ready to harvest, when the water is drawn off and the ground permitted to become dry enough to support the harvesting machinery.

Most farm crops perish in a water-logged soil—While all plants require water for their growth, yet the ordinary farm crops, excepting rice, perish if the soil is saturated with water for any considerable length of time. The conditions essential to the perfection of such crops are occasional saturation of the soil, as by rain in humid climates and by irrigation in arid countries, followed by periods during which the free water of the soil is withdrawn, leaving only a film of moisture surrounding the soil particles, and permitting access of air.

Soil water and the nitrogen supply—These facts are explained by a study of the processes by which nitrogen is made available to plants. Bacterial studies have shown that there are several steps in these processes, all dependent, primarily, upon the actions of living organisms, which have been described in Chapter IV under the heads of nitrogen fixation, ammonification and nitrification. Nitrogen fixation can take place only in the presence of air, but for the conversion of the combined nitrogen of the organic residues in the soil into ammonia air is not necessary, since ammonia is composed of nitrogen and hydrogen, and the hydrogen may be derived from the same residues as the nitrogen, the two elements being recombined in a different form by the action of the ammonifying bacteria, some of which are anaërobic, that is, capable of obtaining their oxygen from other sources than the free oxygen of the air. Nitrification, however, requires the presence of atmospheric oxygen, and hence cannot take place under water. Such plants, therefore, as are able to assimilate nitrogen in the form of ammonia will thrive in water-soaked soil, whereas those plants which can only use nitrogen when combined with oxygen must have a soil through which air can circulate.

The difference between land plants and aquatic plants is analogous to that between land animals and fishes. Each is adapted to its environment and neither can exist under the conditions essential to the life of the other.

The function of drainage, therefore, is to set up and maintain in the soil the conditions essential to the processes by which nitrogen is made available to such plants as require nitrates for their nutrition.

Ammonium salts as fertilizers—It is true that ammonium salts, especially the sulphate, are successfully used as carriers of nitrogen in fertilizers, as well as such organic materials as tankage, dried blood and the oil-meals, but in farm practice these substances are used under conditions which facilitate the transformation of their nitrogen into the nitrate form.

Drainage draws air into the soil—Drainage not only removes excess of water, but as the water level is lowered the air is drawn after it, thus supplying the nitrifying organisms with the oxygen required for their function. As the water descends it not only draws air after it, but it carries with it some of the combined plant food which has been formed in the surface layer. This would seem to involve a loss of soil fertility by drainage, and in the case of very shallow drainage some such loss may occur; but, if the water must descend through two or three feet of a soil containing a considerable percentage of clay before it reaches the drains, the major part of its fertilizing constituents will be absorbed and held upon the surfaces of particles of clay, or seized upon by the soil organisms attached to these particles and utilized in their growth.

Filtration—The purification of sewage by filtration depends upon this principle. The filter consists of beds of sand upon which the sewage is turned and from which the water is slowly drawn away by underdrains. Several beds are employed alternately so that there may be time between floodings for air to enter. Crops are frequently grown on these filter beds, and the water which flows away from them is clear and odorless.

Methods of drainage—The earliest drains were open ditches; these are objectionable, because of their obstruction to tillage, the land they occupy and their tendency to fill up. The next step in drainage was to make an underground channel for the water by placing stones or poles on the sides of the ditch and laying slabs of stone or of wood across these and filling the ditch with earth. This was a great improvement because it made it possible to work over the drains, but the wooden drains were short-lived and the stone drains were only practicable in regions convenient to supplies of suitable stone.

In 1835 John Johnston, a farmer of Scottish ancestry living near Geneva, N. Y., imported from Scotland some clay tiles made for land drainage, and from that beginning the use of tiles for drainage has become universal in America, open ditches being used only where the volume of water at some seasons becomes too great for economical carriage by tiles, or where the farmer is unable to purchase the tiles.

In the making of a tile drain the first step is to secure an outlet, which may be a natural stream or channel, or an open ditch. It is important that this outlet be sufficiently deep to permit a ready flow of water from the tiles. The channels for the tiles are dug either by hand or by machines made for the purpose. In the case of hand digging special tools are used, and an expert ditcher will remove only enough earth to admit the tile, finishing the grade at the bottom with a scoop made for the purpose. It is of course important that there should be such a grade as will permit the continuous and unobstructed flow of water from the head of the drain to its outlet. Numerous machines have been invented for this work, the most satisfactory of which are self-propelled, steam or gasoline driven machines, which cut the drain to full depth at one operation by means of scoops upon a revolving wheel, or belt, and which may be so regulated as to give a perfect grade.

The depth of the drain should be sufficient to place the tiles below the action of frost, for while a well-burned clay tile or a cement tile made of good material should not be affected by frost there is always danger of an inferior tile escaping detection in laying, and the usefulness of a tile drain is measured by its weakest tile, just as the strength of a chain is limited by its weakest link. Usually drains are found to be safe at a depth of thirty inches to three feet. At a much shallower depth than this there will be not only a greater danger of breakage of the tiles from freezing or other accident, but also greater possibility of loss of nitrates and other fertilizing substances. It is feared by some that in stiff clay soils the water will not reach the drains at this depth, but experience has shown that this fear is groundless. The channel cut through the clay in making the drain so breaks up the stratification of the soil as to leave a permanent seepage way to the drain below.

The distance apart at which drains should be placed varies with different soils and with the purposes to which the land is to be devoted. For retentive clay soils the commonly accepted distance is two rods, but this distance is sometimes too great for the best results. In more porous loams or sandy soils the distance may be increased, but usually it is better to increase the depth also if the drains are laid farther apart than two rods. There are some soils which are partially or wholly drained by beds of gravel or by stratified rocks lying near the surface. On such soils the drainage engineer should be guided by the character of the sub-strata.

The size of the tiles is governed by the fall and the area to be drained. It is seldom advisable to use tile smaller than three inches internal diameter, and that size should be used only for lines not exceeding 15 to 20 rods in length, but it is not necessary to increase the size of the main drains proportionately. With a fall of two inches in 100 feet, it is estimated that a 10-inch main will drain 100 acres of average land, but this estimate must be modified to meet special conditions.

Underdrainage conserves moisture—Undrained land soon becomes so saturated with water that it can hold no more and much of the rainfall flows off over the surface, but when the land is underdrained it becomes more porous, and while the free water is removed more rapidly the area accessible to the roots of plants is deepened and thus they have access to a larger store of the film moisture, which is their chief dependence for water. Underdrainage, therefore, reduces the effect of drought instead of increasing it, as some suppose.

Underdrainage reduces floods—The increase in the volume of floods as the forests are removed and the land is brought under cultivation is due to the facilities offered for the rapid escape of surface water by surface drainage through open ditches, especially those along roadsides. Underdrainage tends to reduce the floods by storing a larger proportion of the rainfall in the soil, from which it escapes more slowly than from surface drained land.

If the land is not underdrained it soon becomes saturated with water and as there is almost no evaporation during the winter season, when the spring rains come the water will practically all flow off over the surface; but if the land has been underdrained the excess of water will have been carried out of the lower strata of the soil during the winter and it will be ready to absorb a much larger proportion of the rainfall, the excess of which will be carried off comparatively slowly through the drains.

Drainage lengthens the season—By removing the excess of water drainage makes it possible to begin working on the land earlier in the spring and sooner after summer rains, so that drainage very materially extends the season through which crops may grow, and gives opportunity for more thorough cultivation.

Drainage warms the soil—A wet soil is a cold soil, because water conducts heat much more slowly than earth. Consequently a water-soaked soil will be later in becoming warm in the spring than one which has been drained, and will maintain a lower average temperature throughout the season.

II.—IRRIGATION

As the object of drainage is to remove excess of water, that of irrigation is to make up for deficiency of water. Some of the oldest agricultural works are the remains of ancient irrigation canals in Babylonia and Egypt, some of which were constructed 20 centuries or more before the Christian Era, while in America irrigation was practised by the prehistoric people who inhabited Arizona and New Mexico, long before the advent of the white man. In modern times this system has been revived in extensive works in Egypt and India, and in the semi-arid region of the western United States.

The practice of irrigation consisted originally in impounding the waters of rivers by means of dams and conducting the water by canals to lands lying at lower levels, over which it was distributed through smaller canals and ditches or furrows, the flow of water being regulated by gates in the larger canals and by use of the plow and hoe in distributing it over the fields. In ancient Egypt and India water was sometimes lifted out of the rivers by water wheels turned by man or animal power and then distributed over the land by gravity, and in modern practice pumps driven by windmills or engines are occasionally utilized for this purpose. By a recently devised system water is distributed through systems of overhead, perforated pipes, from which it falls as a spray upon the land, this system being confined to gardens.

The object of irrigation, as stated above, is to supply water to soils which do not receive a sufficient quantity of rain. It is therefore limited to regions in which the rainfall is deficient; or, in humid countries, to supplementing this rainfall during occasional periods of drought. In such regions it is only practised in the culture of crops of high relative value, such as garden crops, fruits, etc.

As land increases in value the necessity for increasing its yield and for guarding against the losses incident to lack of water in dry seasons will increase the attention given to irrigation, and on farms where the conditions are favorable for taking water from streams, or for storing it in reservoirs, this practice will become more and more prevalent.

III.—TILLAGE

The first object of tillage is to obtain a bed of loose earth in which to bury the seeds or roots of plants which we wish to propagate. In accomplishing this end we also turn under or destroy the plants previously occupying the ground and which we wish to replace with others more useful, and we so loosen the soil that the rootlets of the young plants may permeate it more easily. By tillage, moreover, we incorporate with the soil manures and other fertilizing materials. In fact, the word manure is derived from the French word "manoeuvrer," to manipulate, to work, and originally manuring and cultivating were indicated by the same term; but tillage has two other important functions, namely: the promotion of nitrification in the soil and the conservation of its moisture.

Tillage promotes nitrification by facilitating the circulation of air in the soil, thus furnishing oxygen to the soil organisms, and by re-distributing the nitrifying bacteria, thus bringing them into contact with new material.

In the making of yeast bread the housewife takes a quantity of yeast, which is a fungous plant, mixes it into a "dough" with flour and water and sets it in a warm place to "rise." That is, she gives the yeast plant the conditions of warmth and moisture which are essential to all plant growth, and furnishes it with plant food in the mineral elements and the carbon, hydrogen and oxygen of which the flour is composed; starch, the chief constituent of flour being composed of these three elements, while every grain of wheat also contains nitrogen, together with minute quantities of phosphorus, potassium, calcium, magnesium, sulphur and iron, with occasional traces of other elements. After the yeast plant has grown for a few hours the dough is thoroughly "kneaded," by which operation the yeast is more thoroughly distributed; the dough is then set aside to rise again, after which it is baked. The rising or lightening of the bread is due to the evolution of carbon dioxide in the growth of the yeast, this gas inflating the dough much as soap bubbles are inflated when blown from children's pipes.

While the nitrifying bacteria are very different from the yeast fungus, there is a general resemblance in the conditions controlling their work. Like yeast, they are plants, and therefore they require warmth and moisture for their growth, and their growth is increased by such methods as will tend to their more uniform distribution through the soil.

Tillage does more than kill weeds—The knowledge of nitrification thus explains the familiar fact that tillage increases the yield of summer crops to a greater extent than can be accounted for by the mere destruction of competing weeds, and also explains the fact that corn, a crop which is grown through the summer only, and which receives just the treatment calculated most effectively to promote nitrification, in the four or five cultivations which it receives during that part of the summer when the conditions are most favorable to the growth of the nitrifying organisms, is able to secure nearly twice as much nitrogen from an acre of land as wheat would obtain from the same acre; wheat being a crop which makes the larger part of its growth during the cooler weather of the early spring when the conditions are less favorable for the work of the nitrifying bacteria, and wheat also being grown without the stirring of the soil during the growth of the crop that is given to corn.

At the Ohio Experiment Station corn and wheat, an acre each, have been grown continuously side by side for 35 years in succession. Where no manure nor fertilizer has been applied except ground limestone the corn has produced an average yield of 13.9 bushels of grain and 887 pounds of stover, estimated to have carried 25 pounds of nitrogen, and the wheat has averaged 7.34 bushels of grain and 745 pounds of straw, estimated to have carried 12.5 pounds of nitrogen. Since the rainfall carries to the land 5 or 6 pounds of nitrogen annually, it is seen that the corn must have obtained more than twice as much from other sources as the wheat.

Intertillage of wheat—Experiments have been made in growing wheat in rows sufficiently far apart to permit intertillage, but, in the case of winter wheat especially, the advantage of such cultivation has not been sufficient to justify its cost where labor is so expensive as in America. In the case of corn and other crops that grow through the summer the cultivation is chiefly done while the plants are small and before the roots have occupied the land; but the wheat roots spread through the soil during the fall and early spring, so that it is difficult to cultivate by machinery without considerable interference with their growth. In sections of China, however, where labor is cheap and land so valuable that every square yard that can be cultivated is kept constantly under the plow, wheat is regularly hoed by hand, and yields are sometimes obtained that compare with those obtained from corn in America.[1]

Tillage conserves moisture—In the early spring, in humid climates, the soil is saturated with moisture from the winter snows and rains, which is gradually withdrawn by evaporation under the increasing warmth of the sunshine. If the weather be dry and the land be left undisturbed it will dry out to such an extent that clay soils will become so hard that when the attempt is made to plow them they will break up in large clods which can only be pulverized with great difficulty. If, however, the plowing be done as soon as the land has reached the proper condition of moisture, neither too wet nor too dry—a condition which is indicated by the upturned furrow slice crumbling readily, instead of retaining its form and showing a smooth, cohesive, glistening surface—and the plow is promptly followed with the harrow, leaving a finely pulverized surface, the land will remain moist in dry weather for a much longer time than that which has not been plowed. If, however, a driving rain should come a crust will be formed over the surface, rapid evaporation will take place and the land will soon become hard, unless the crust be broken with the harrow. Tillage, therefore, when properly conducted, serves to reduce evaporation and thus to conserve moisture.

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[1] King, "Farmers of Forty Centuries."

On the other hand, if the plowed land be left without harrowing the furrow slices will expose a larger area to the action of sunshine and wind, the cracks in the furrows will admit the air, and the land will dry out more rapidly than if it had not been plowed.

The use of the roller—It is a too common practice to follow the plow with the roller, either immediately, or after the plowed land has been allowed to dry out for hours or days, and to neglect harrowing. The roller cracks the clods and passes over the holes made by the horses' feet without filling them, and the land so treated dries out all the more rapidly because of the rolling. When the roller is immediately followed by a drag or harrow, to fill the holes and crevices with finely pulverized earth, the combined work of the two implements covers the surface with a mulch of fine earth which retards evaporation and thus retains the moisture in the soil; but if the harrowing be neglected the roller will do more harm than good. Properly used, the roller is one of the most useful implements on the farm, but on many farms it is so used as to be an injury, instead of a benefit, to the land. Fluted rollers are now made that compress the soil both vertically and horizontally, thus filling the cracks caused by the vertical pressure. Such rollers are much to be preferred to the plane-surfaced implements.

Tillage in the cornfield—The general principles of tillage apply to the cultivation of the corn crop as well as to the preparation of the land for it. A corn crop yielding 100 bushels of shelled grain to the acre will carry in its ears, stover and roots, fully five tons of actual dry substance, and for each ton of such dry substance at least 300 tons of water must have passed upward through the corn plants and into the atmosphere during the growth of the crop; so that to produce 100 bushels of corn 1500 tons of water is required, and this water must be furnished between the first of June and the middle of September.

An inch of rainfall weighs about 100 tons to the acre, so that 15 inches of rainfall would be required to furnish the water for such a crop of corn, if all the water of the rain were utilized by the crop. But the average rainfall for Ohio during the corn growing season is only a little more than 12 inches and in the western states of the cornbelt it is less than this; moreover, a very large part of the rainfall is evaporated directly from the land, so that we cannot hope to attain the maximum yields of our cornfields if we depend wholly upon the rain which falls during the growing season. For this reason the conservation of as much as possible of the moisture accumulated in the soil during the winter and spring is a matter of first importance if maximum crops are to be grown.

Cultivation should conserve moisture—Not only this, but the cultivation of the corn while growing should be such as to preserve the soil moisture, by exposing as small a surface as possible to the drying action of sunshine and wind, and by keeping this surface finely pulverized. In the old method of cultivating corn, cultivators with large shovels were used and these were run as deeply as possible, so that the land was left in small ridges, thus exposing as much surface as possible; but this method is no longer practised by the more careful farmers; the harrow is used for the first working and this is followed by cultivators with small shovels, set to run shallow, and leaving the land as level as possible. Care is taken, too, to break up the crust which is formed by dashing rains, as such a crust means that the soil has become so compacted as to afford a continuous capillary connection between the subsoil and the surface. This connection should be broken by pulverizing the surface, thus forming what is called a "dust mulch."

The mulch as a conserver of moisture—The boy hunting for fish bait turns over the loose boards or small piles of straw or other litter and finds the ground under them loose and moist, after that all around has become dry and hard. The board or the litter has kept the ground shaded and protected from the wind and has thus conserved its moisture. Any material that will serve this purpose may be called a mulch.

The mulch in the orchard—Orchard trees are very large consumers of water, because of their great expanse of foliage. Moreover, notwithstanding the watery character of the fruit, the seeds which it contains are composed of the same elementary substances as are the seeds of grains and other farm crops, so that if an orchard is to maintain its fruitfulness the supply both of water and of the plant food elements must be looked after.

VIII

The Function of Lime in the Soil

FROM time immemorial the fact has been recognized that soils derived from limestones are usually more productive than those derived from granites, sandstones or shales, a fact that has given rise to the proverb, "A limestone country is a rich country," and long before the value of mineral phosphates or potash salts was discovered limestone was burnt and spread over the land; but so late as the first edition of his great work, "Agriculture in some of its Relations with Chemistry," Professor F. H. Storer wrote:

> "The theory of the use of lime as a manure is a subject full of interest and importance, as well as of doubt and apparent contradiction. In some regions the farmers are seen to apply lime well-nigh universally, and in such quantities, indeed, that at certain seasons of the year the whole surface of the country is made white with it; while in other places it is easy to perceive that lime is held in small esteem by practical men.
>
> "It is hard to say positively why opinions should differ so widely, or to discover all the reasons which have determined the observed variations of practice. In one word, the subject of liming land is not yet thoroughly understood in all its bearings."

This work was published in 1887, but was written earlier. At the time it was being written English, French, German and American investigators were trying to discover the method by which the nitrogen supply of our crops is maintained. The first step towards this discovery had been made by Pasteur and was recognized by Storer, in the demonstration that the process known as fermentation, which had previously been supposed to be purely chemical, was in fact due to the work of living microörganisms—microdemes, Storer called them. The next step was the discovery, made in Germany and published in 1886, that the superior ability of the clovers and other leguminous plants to secure nitrogen is due to the organisms inhabiting the nodules found on their roots, and a third step was the later discovery of the organisms by which the free nitrogen of the air circulating in the soil is directly combined with oxygen and the mineral elements; these, together with the nodule formers, restoring to the soil the nitrogen that is constantly escaping during the processes of fermentation and decay.

Lime increases the nitrogen supply—The relation of these discoveries to the lime question lies in the fact that the presence in the soil of an alkali of some sort is essential to the growth of these organisms, since the product of their work is the combination of nitrogen and oxygen into nitric acid, which would accumulate in such quantity as to be toxic to the organisms producing it were it not converted into a neutral salt by union with an alkali. Other alkalies than lime would serve this purpose, soda for example, but the abundance and consequent cheapness of lime makes it the material to use.

Lime thus serves the double purpose of furnishing the plant directly with two elements, calcium and magnesium, indispensable to its growth, and also of indirectly increasing the supply of nitrogen, through its support of bacterial action. It also performs another important function in modifying the physical condition of the soil.

Quantity of lime in the soil—The amount of lime found in different soils varies widely. In their study of the soils of Ohio Ames and Gaither[1] found as little as 3,200 pounds of calcium and 5,512 pounds of magnesium and as much as 131,902 pounds of calcium and 55,584 pounds of magnesium in the upper 6 inches of an acre. Computed as carbonate these figures would indicate a range of from 10 tons to 230 tons of limestone per acre,[2] but these investigations have shown that in the smaller quantities little or no carbonate is found in the soil, the calcium and magnesium having entered into other combinations that are less available to crops than the carbonates, the result being that the small addition of a few tons of limestone per acre to such soils has produced a marvelous change; not only have the crops been greatly increased, but the soil itself has taken on a darker color.

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[1] Ohio Experiment Station Bul. 161.

[2] The weight of an acre of average soil, taken to the depth of 6 inches is estimated at about 1,000 tons.

The physical effect of lime—The direct feeding of the plant is only one of the functions of lime. Soils in which clay is the predominant constituent sometimes become so depleted of their organic substance, by constant cropping and neglect of means for maintaining the humus supply, that the fine particles of clay become so closely packed that water can scarcely penetrate them; consequently much of the rain which falls on them flows off over the surface, and thus the supply stored in the soil is insufficient to furnish the stream of nutrient material which must pass upward through the plant if a vigorous growth is to be sustained. Moreover, water circulates so imperfectly through the closely packed mass as to impede the work of the soil organisms, through whose agency in part the crude mineral elements are transformed into nutrient form, while the crops are unable to send their roots freely through the dense soil in search of their food. The consequence is a stunted and unprofitable growth on a soil that might be capable of furnishing all the mineral elements of fertility in abundance, were it only kept in such physical condition as to permit the most effective storage and circulation of water and air.

Flocculation—The condition of such a soil may be improved by incorporating with it a very small percentage of lime, the effect of which will be the collection of the fine soil grains into larger particles—a process called flocculation—the lime thus performing the double function of facilitating the circulation of water, air and plant roots and of furnishing the alkaline base necessary to the work of the soil bacteria.

Experiment

To a pound of pulverized dry clay add a quarter of an ounce of powdered quicklime; mix thoroughly, then add enough water to bring the clay to the consistency of putty and roll it into balls half an inch in diameter.

> Make a similar lot of balls of the same clay without the addition of any lime. Set all away until dry, when it will be found that the balls containing lime will crush very much more easily than those without lime. So small a quantity of lime as one-half of one percent, which would be only 5 tons per acre of the upper 7 inches of the soil, will have a very marked effect.

Lime on sandy soils—Loose, sandy soils, that is, those just the opposite of clays in texture, may also be improved by liming. Such soils not only are usually derived from rocks deficient in lime, but their texture is such as to involve a relatively rapid loss of lime through leaching, because of the readiness with which carbonate of lime goes into solution and is thus carried out in the drainage. Liming promotes the growth of plant roots and thus increases the organic matter and makes the soil more retentive of moisture.

The comparative ease with which limestone is dissolved is illustrated by the caves in limestone regions. These have been hollowed out by the solvent action of water, which has dissolved the limestone and carried it away, sometimes to the sea, sometimes to be redeposited in beds of precipitated marl, formed where the lime-laden water has come to the surface and by evaporation has been forced to give up a part of its load, just as it is doing every day in the kitchen teakettle and the steam boiler.

Near Covington, Virginia, is a deposit of thousands of tons of marl, formed from the spray of a waterfall, while the magnificent Luray and other caverns, not many miles distant, show how the water, trickling through the crevices of the rock for ages, has dissolved out its substance and carried it away.

These examples show how water, circulating freely through a sandy soil, will remove the lime from such a soil much more rapidly than from one of more compact texture.

The support of the soil bacteria, by whose agency the nitrogen of the air and of the organic substances in the soil is converted into forms available to higher vegetation, is a third, and one of the most important functions of lime. The final product of the nitrifying bacteria is nitric acid, and if this be produced more rapidly than it can be utilized by growing crops it will either accumulate in the soil to such an extent as to be toxic to the organisms producing it, or it will be washed into the drainage waters and lost, unless there be an alkaline base present with which the excess of acid may combine, forming a neutral salt. Lime furnishes the necessary alkaline base and nitrate of lime is formed, which not only prevents the injurious effect of the excess of acid but also serves as a storage battery in which the nitrogen may be held in its combined and available form until the crops can utilize it.

When to use lime.—By understanding more clearly the functions of lime in the soil we shall be able to use it more intelligently and more effectively. Farmers have used lime for centuries, under the guidance of experience, but our present knowledge of the principles governing the growth of crops shows that lime has often been used extravagantly and wastefully, and more often has not been used at all when it was urgently needed.

The geological origin of the soil is the first point to be determined in the case of a soil on which the use of lime is being considered. If the underlying rock be limestone, or limestone gravel, it is generally safe to assume that lime is less likely to be needed than if the land lies over sandstones or shales. But the surface, even of soils once rich in lime, may in time become so depleted by exhaustive cropping as to make it necessary to replenish the lime supply. It must not be forgotten that a soil which has been modified by glacial action may have been derived from rocks entirely different in character from those over which it lies, for the glacier, in its southward march, may have gathered its materials largely from one class of rocks and deposited them chiefly upon another.

Again, if the soil has been transported by water it is necessary to know something of the character of the land from which the floods have stolen the treasure which they have spread over other fields.

The previous history of the farm is an important factor in determining the probable lime requirement, for if the policy has been to sell everything off the farm, hay and straw as well as grain, the soil will have been depleted of its lime very much more rapidly than if grain only has been sold, for the stems and leaves of the cultivated crops contain much more lime than the grain, as is shown in Table 1, page 45.

Even in pasturing there will be a large withdrawal of lime, whether the pasturing be for the growth of animals or the production of milk, for lime constitutes the larger part of the weight of bone, hence milk, the natural food of the young animal, must contain bone-forming material in abundance.

For these reasons the man who would treat his soil with the greatest effectiveness must have an intelligent knowledge of its geological origin and human history, as well as of the chemical relations of soils and crops and animals.

Red clover as an index to the lime supply—Considering the much larger quantity of lime found in a crop of red clover than in an equivalent yield of most other crops, it would be expected that clover would be one of the first crops to suffer from lack of lime in the soil, and experience has shown this to be the case. Under such conditions it is difficult to get a stand of clover in the spring. The young plants are weak and easily destroyed by unfavorable conditions, such as frost or drought. It is a common experience, on an acid soil, for the fields of young clover to show a spotted and irregular growth after the wheat or oats with which the clover was sown has been harvested. There may be patches of good clover in the depressions where the water supply is better, or on places where log heaps were burned in the clearing of the land, alternating with larger or smaller areas over which the clover remains stunted and almost entirely disappears by the following spring, its place to be taken by sorrel. In seasons of abundant rainfall this condition will not be so noticeable, the plentiful water supply bringing more of the scanty lime into solution, but in seasons of drought the poor areas will increase until they may occupy nearly all the land.

Clover, however, is subject to other limitations than lack of lime—It must have phosphorus and potassium as well as lime, and if the soil has been depleted of these elements the clover cannot thrive. For example, at the Ohio Station the following average yields of clover have been obtained during a 20-year period on land that has had the treatments indicated:

TREATMENT	*Pounds of hay per acre*
No fertilizer, no lime	846
Phosphorus and potassium, no lime	1,237
Lime only	1,950
Lime, phosphorus and potassium	3,076

Moreover, red clover is liable to attack from insects and disease which may materially affect its yield; for these reasons observation of the behavior of the clover crop should be supplemented by tests for soil acidity, the simplest of which is the litmus test.

The litmus test—This test for acidity is easily made with litmus paper, a blue paper which has been chemically prepared so that when moistened with an acid solution its color will be changed to red, while an alkaline solution will leave the color unchanged.

Experiment

Procure a few slips of litmus paper from a chemical laboratory or drugstore. Insert a knife blade into the soil to be tested, which must be moistened with water if it is not already wet. Test the water with the paper to make sure that it will not affect the color of the paper, and be careful that the knife blade is free from any acid or alkali. It is well to wipe the knife blade with a clean cloth before using it. Withdraw the knife blade, insert a strip of litmus paper and press the soil around it. After a few minutes remove the paper without tearing it and rinse the soil from it with clean water. If the soil is acid the paper will have turned to a pinkish color, but if it is neutral there will be no change in the color of the paper except the darkening due to the moistening.

Another way to make the test, which is especially useful in case the soil is dry, is to mix the soil into a paste in a saucer or similar dish and insert the litmus paper in this paste.

Whichever method is employed, great care must be taken to see that the water and all dishes used are free from acid or alkali.

To study the behavior of litmus paper, dip it alternately in vinegar and in water in which baking soda has been dissolved. Of course no soil will be found in which the acid or alkali will be so strong as in vinegar or soda.

The litmus test shows whether the soil is acid or not, and to some extent indicates the degree of acidity and thus suggests the amount of lime required for neutralization. Numerous attempts have been made to devise a test that would measure the lime requirement more accurately, but for ordinary use on the farm the litmus test is sufficient to show whether lime is becoming deficient.

Chemical tests alone not sufficient—But no chemical test alone should be accepted as a guaranty that the soil will respond profitably to liming. If the soil has been derived from sandstones or other non-calcareous rocks, and if red clover is failing to grow, it is safe to assume that systematic liming will pay; but where the rock foundation is limestone or glacial drift of limestone origin, there may be old fields in which the surface shows acidity while the subsoil is still neutral or alkaline. In such situations the deepening of the plow furrow by an inch or two may be more effective than liming. There probably also are areas in the limestone regions where a single dressing of limestone would be paid for with interest in 8 or 10 years but which would not justify a more frequent repetition of the treatment.

Some crops require less lime than others—Potatoes are grown successfully on land that is becoming too acid for the best growth of clover. Alsike clover and soybeans may be grown successfully for some time after the land has become too acid for the medium or common red clover, while alfalfa and sweet clover (Melilotus) are even more sensitive to lack of lime than red clover.

This sensitiveness to presence or absence of lime is shown in a marked degree by certain forest trees. For example, the chestnut is practically never seen on a limestone soil except in artificial plantations, and there it is usually unthrifty, while the yellow locust is conspicuous for its partiality to such soils. This point is strikingly illustrated in the hill counties of southeastern Ohio, where many of the hills are capped with limestones, lying over strata of sandstones and shales. A locust grove in this region is a sure indication of a limestone cap or outcrop. On the other hand, the white-oak appears to be indifferent to lime, growing equally well over limestones and sandstones.

Some common weeds and lime—The ragweed *(Ambrosia artemesiaefolia)*, which takes possession of the wheat stubble fields after harvest in limestone regions, makes a comparatively feeble growth on acid soils, while the sorrel *(Rumex acetosella)*, becomes so conspicuous on soils of the latter class that its presence is regarded as one of the first indications of lack of lime. Sorrel, however, may grow thriftily in a limestone soil. Its presence in the sickly clover fields of the acid regions appears to be due to its ability to grow without the help of lime, and the failure of the clover gives it its opportunity. The plantains resemble sorrel in this respect. Sweet clover is found only where there is plenty of lime. In regions of acid soils its growth is confined to the neighborhood of railroads or other roads which have been ballasted with limestone, or to spots which have in some way preserved their lime supply. The burning of a log heap, for example, in clearing off the forest growth, may leave a spot so stocked with lime that the clovers will thrive there long after the soil in general has become too acid for their growth.

Lists of plants sensitive or non-sensitive to lime deficiency—The Rhode Island Experiment Station has made an extensive study of this question by growing plants on the very acid, granitic soil of that Station, the results of which have been published in Bulletin 160. From this bulletin, from personal observation and from other sources the following lists have been compiled, in which some of the more common plants are grouped according to their relative indifference to lime deficiency in the soil.

Plants relatively indifferent to soil acidity

Apple
Basswood
Bean
Beech
Birch
Buckwheat
Brome grass
Cherry (wild and cultivated)
Chestnut
Cotton
Cowpea
Cranberry
Dogwood
Elderberry
Elm
Flax
Grape
Hemlock
Lupine
Maple
Meadow oat grass
Millet
Norway Spruce
Oak (white and red)
Oats
Peach
Peanut
Pear
Plum
Potato (white)
Quince
Raspberry
Red top grass
Rhode Island Bent grass
Rice
Rye
Squash (white bush)
Strawberry

Plants relatively sensitive to soil acidity

Alfalfa
Arbor Vitae, American
Asparagus
Barley
Beet
Bluegrass
Cabbage
Catalpa
Cauliflower
Cedar, Red
Clover, Medium Red
Clover, Sweet
Corn
Cucumber
Hemp
Hickory
Lettuce
Locust, yellow
Muskmelon
Onion
Parsnip
Pea
Rhubarb
Sheep's fescue
Soybeans
Spinach
Sunflower
Tall Fescue
Timothy
Tomato
Walnut

Plants relatively indifferent to soil acidity

Tobacco
Turnip
Watermelon
White pine

The first list is the longer because of the number of trees included. If we limit this list to agricultural crops it will include most fruits; buckwheat, flax, rye and oats among the grains; beans, the cowpea (which is a bean), lupines and peanuts among the legumes; brome grass, meadow oat grass, millet, red-top and Rhode Island Bent among the grasses, and the potato, bush squash, turnip and watermelon among the truck crops. All these crops thrive equally well on limestone soils, but they are the crops to which preference should be given by those whose soil is acid and so located as to make the cost of liming prohibitive.

Corn, wheat, soybeans, tomatoes, alsike clover, mammoth red clover and timothy are somewhat less sensitive to acidity than the other crops mentioned in the second list, but will not give full yields on very acid soils. The trees named in this list may be grown on acid soils, but they are seldom found on such soils except when transplanted.

IX

Field Experiments in Liming the Land[1]

I.—EASTERN SOILS

Massachusetts—In 1899 the Massachusetts Experiment Station began the addition of lime to half of each plot of a tract of land that had been under an experiment in which different combinations of fertilizing materials had been used for eleven years, each plot having been continuously treated with the same fertilizers, while the cropping had been an irregular rotation of field and truck crops. Hydrated lime was applied to part of the land at the rate of one ton per acre in 1899 and 1904, and of one-half ton in 1907, and ground limestone was given in 1916 at the rate of two tons per acre.

Onions were grown the first three years, after which an irregular rotation was followed in which the land was occupied about half the time with hay crops. A mixture of timothy, red top, mammoth, red and alsike clovers was first sown, but the clovers refused to grow on the unlimed land.

During the period 1899 to 1918, two crops of onions, one of potatoes, six of hay, two of corn, three of soybeans and one each of rye, cabbage and yellow-eye beans were harvested, and one crop each of onions, hay and soybeans were grown but not weighed separately. The onions showed a large, but somewhat irregular increase from liming. Taking the yield on the land receiving per acre 320 pounds nitrate of soda, 640 pounds dissolved boneblack and 320 pounds muriate of potash, the average yields of onions for the two years, 1899, 1900, were 356 bushels per acre on the limed land, against 91 bushels on the unlimed land. The cabbage, grown in 1917, yielded 21¼ tons of hard and 1½ ton of soft cabbage on the limed land, against 13 tons of hard and 3¾ tons of soft on the unlimed land.

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[1] See also Chapter XI and TABLE XIX.

The total yields of the field crops and the increase for liming, under the different fertilizer treatments, are shown in Table 3, the fertilizer applications for these crops, excepting the potatoes, having been half the quantities given to the onions. The potatoes received the same quantities given to the onions.

TABLE III.—EFFECT OF LIMING MASSACHUSETTS SOILS
TOTAL YIELDS ON LIMED AND UNLIMED LAND

CROP	*Number of crops*	*Fertilizer treatment* [2]			
		N & P	*N & K*	*P & K*	*N & P & K*
Hay, limed, lbs.	6	21,700	20,990	23,800	29,230
Hay, unlimed, lbs.	6	13,710	11,230	4,890	14,680
Corn, limed, bus.	2	70.48	75.23	82.34	94.26
Corn, unlimed, bus.	2	63.54	37.57	41.17	74.54
Soybeans, limed, bus.	3	35.00	53.80	45.86	50.86
Soybeans, unlimed, bus.	3	32.24	32.42	26.04	33.28
Potatoes, limed, bus.	1	100.30	75.60	113.70	132.60
Potatoes, unlimed, bus.	1	98.00	77.30	91.70	127.30
Rye, limed, bus.	1	35.30	35.30	31.10	35.70
Rye, unlimed, bus.	1	27.90	22.90	17.10	21.80

P—320 lbs. dissolved boneblack.
K—160 lbs. muriate of potash.
(Double these quantities on potatoes).

In the next table the values of these crops are computed at the low prices of ten dollars a ton for hay, 50 cents a bushel each for corn and potatoes, a dollar and a half for soybeans and one dollar for rye.

TABLE IV.—EFFECT OF LIMING MASSACHUSETTS SOIL
VALUE OF INCREASE FROM LIMING

FERTILIZER TREATMENT	*Total value of produce*		*Value of increase from liming*
	Unlimed	*Limed*	
Nitrate of soda and acid phosphate	$226	$282	$ 71
Nitrate of soda and muriate of potash	185	296	111
Acid phosphate and muriate of potash	147	317	170
Nitrate of soda, acid phosphate and muriate of potash	246	371	125

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[2] N—160 lbs. nitrate of soda.

The outcome indicates that muriate of potash has increased the lime requirement of the soil and that nitrate of soda has reduced it, though not sufficiently to make liming unnecessary; the smallest increase from liming being sufficient to greatly overbalance its cost in these crops of comparatively low value, saying nothing of the much larger financial return shown by the truck crops that are not included in the foregoing computation.

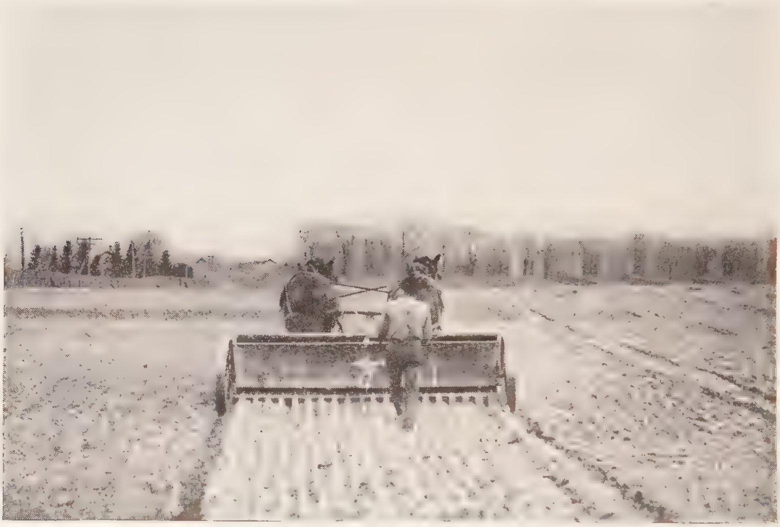

FIGURE III.—SPREADING LIME

Not all land needs lime, but where it is needed the lime spreader is a necessary implement if lime and labor are to be employed with economy. No hand spreading can equal in uniformity that done by a good machine, and if the lime is fully to serve its purpose a particle of lime must be in contact with every particle of soil. Photo by C. A. Gearhart, Ohio Experiment Station.

The soil upon which this test has been made is a terrace soil of the Connecticut River Valley, derived largely from granitic detritus.[3]

New Jersey—Since 1908 the New Jersey Experiment Station has conducted two series of field experiments on plants grown on one-twentieth acre plots on a sandy loam soil, in one of which corn, oats, wheat and two years of timothy were grown in a five-year rotation without any leguminous crops, and in the other the same and other crops were grown in four different rotations in which leguminous crops were introduced, either as one of the main crops or as green-manure crops between the main crops.

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[3] Mass. Exp. Sta. Bul. 212.

Lime in the carbonate form, carried either in finely ground calcium limestone or oyster shells, was used in the first series, at the rate of one ton of stone per acre for the first five years and of two tons for the second five years.

In the absence of leguminous crops the limed and unlimed land gave practically the same yields during the first five-year period. During the second five years there was a slight gain for the liming, but this was fully offset by losses of nitrogen from the soil. In the second series calcium limestone was used on half the land and magnesian limestone on half, the quantities in both cases being one-half ton, one ton and two tons per acre on different plots. In this series the limed plots yielded distinctly larger crops during the 10 years than the unlimed plots, and in most cases the yields were larger for the one-ton and two-ton dressings than for the smaller one.

There was a slight difference in favor of the magnesian limestone.

In the majority of cases the percentage of nitrogen was higher in the limed than in the unlimed crops, and analyses of the soil showed generally an equal or higher percentage of nitrogen at the end than at the beginning of the ten-year period.

All the land received moderate dressings of chemical fertilizers.

The conclusion reached by the experimenters is that "in using lime emphasis should be laid on its power to make conditions favorable for the organisms associated with leguminous crops rather than on its power simply to neutralize soil acids."[4]

Delaware—The Delaware Experiment Station reports the results of 15 years' experiments with manure, fertilizers and lime on corn, oats, soybeans, wheat and clover grown in rotation on a sassafras silt loam soil, from which the following conclusions with respect to the use of lime are drawn:

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[4] J. G. Lipman and A. W. Blair, in "Soil Science," 9 (1920) No. 2, pp. 83-114.

> "The value of lime is limited. It aids in the production of corn and soybeans only where muriate of potash is also applied. Lime does, however, play an important role in the growth of the hay crop (clover and timothy). It produces the greatest gains in connection with applications of muriate of potash and with applications of muriate of potash and nitrate of soda combined." [5]

North Carolina—The North Carolina Experiment Station summarizes its experiments in the use of lime on the Coastal plain, Piedmont and Mountain soils of that State as follows:

> "With soils of all sections of the state, when handled properly and when suitable legumes are grown in rotation with the main money crops and when part or all of the legumes are turned under, it becomes necessary to use lime in most cases in order to secure best results in their improvement." [6]

Virginia—The Virginia Experiment Station is located at Blacksburg, on the western slope of the Blue Ridge Mountains, at an elevation of 2,150 feet above sea level, and on a residual limestone soil, classed as Hagerstown silt loam. In the fertility experiments at this Station 1,200 pounds of quicklime per acre, applied annually to corn and wheat, each being grown continuously on the same land, has increased the annual yield of corn by a 19-year average of 15.4 bushels per acre, and that of wheat by a 9-year average of 11.6 bushels.

When these crops have been grown in a rotation of corn, soybeans and wheat, one year each, and clover and timothy two years, the increase for 11 years, during which two crops each of corn and soybeans, three crops of wheat and two crops each of clover and timothy have been grown, has had an average annual value of $4.86, at the prices hereinbefore employed, produced at the cost of two tons of ground limestone applied once in five years, or the equivalent of 1,600 pounds annually.

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[5] Del. Exp. Sta. B. 138.

[6] North Carolina Dept. Agr. Extension Circular No. 141.

In these experiments the lime and limestone have been used alone, and the effect has apparently been in part to increase the availability of other elements in the soil. The authors of the bulletin[7] in which these experiments are reported say:

> "It is not a good practice to grow corn and wheat on the same land continuously and it is inadvisable to apply nothing but lime to crops. Lime is not a fertilizer, and its use for too long a period without the use of a commercial fertilizer[8] will decrease the fertility of the soil. The experiments reported here were started to make certain chemical studies of the soil and not primarily to secure yields."

II.—SOILS OF THE OHIO VALLEY

A subsurface elevation of the earth's crust, formerly called the "Cincinnati Arch," extends from northern Ohio in a southwesterly direction to the southern part of middle Tennessee, approximately paralleling the Appalachian System.

From western Ohio and eastern Indiana, through central Kentucky and Tennessee the surface rocks of this formation are limestones that dip to the east and west under the shales, sandstones and thin beds of limestone of the coal measures, which extend from northeastern Ohio through West Virginia and Kentucky into eastern Tennessee, and from central Indiana and Illinois into western Kentucky.

The eastern coal fields are separated from the limestones by shales and sandstones of the Waverly series, which cover a large part of northeastern Ohio and extend into Kentucky and Tennessee in smaller areas.

Three or more periods of glaciation have been recognized in this region. (1) The Illinoian, which covered the entire state of Illinois except one county in the northwestern corner and two tiers of counties at the southern extremity of the State, and extended eastward over the larger part of Indiana and western Ohio; (2) the Iowan, covering a comparatively small area in northern Illinois, and (3) the Wisconsin, which covered the northeastern quarter of Illinois, the northern half or more of Indiana and all of Ohio except the southeastern quarter and the southern tier of counties in the southwestern quarter. Some geologists separate the Wisconsin glaciation into two periods, the earlier and later.

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[7] Va. Agr. Exp. Sta. Bul. 253.

[8] (Or manure, C. E. T.)

Between these glacial periods there were long intervals, during some of which tropical conditions prevailed as far north as the Arctic Circle and the great coal beds were formed, and at other times there were long periods of drought, during which the finest of the powder into which the rocks had been ground under the upper millstone of the moving ice was picked up by the wind, carried through the air and redeposited in the layer of loess that covers the greater part of Illinois and extends across southern Indiana and into southwestern Ohio, a layer reaching a thickness of several feet in many parts of Illinois and even of a hundred feet or more in the bluffs along the Mississippi, as far south as Memphis, but thinning to a few inches in Ohio.

If it seems difficult to account for the accumulation of the loess deposits in this way, let us remember that geologic time is measured by millions of years, and that if one year's accumulation of dust were no thicker than a sheet of India paper, thus requiring 250 years to produce a deposit one inch in thickness, within a million years the deposit would attain a thickness of more than 200 feet.

Ohio—The Ohio Experiment Station was removed to its present location in 1892. At that time there was no better authority on the function of lime in the soil than Professor Storer, quoted on page 69. The experience of the then Director of the Station had been gained on the lime-stored soils of the Miami Valley, and the Agriculturist had been trained at the Pennsylvania State College, where liming at that time was giving negative results, the college farm being located on a residual limestone soil. Naturally, little importance was attached to lime as a soil ameliorant, and no

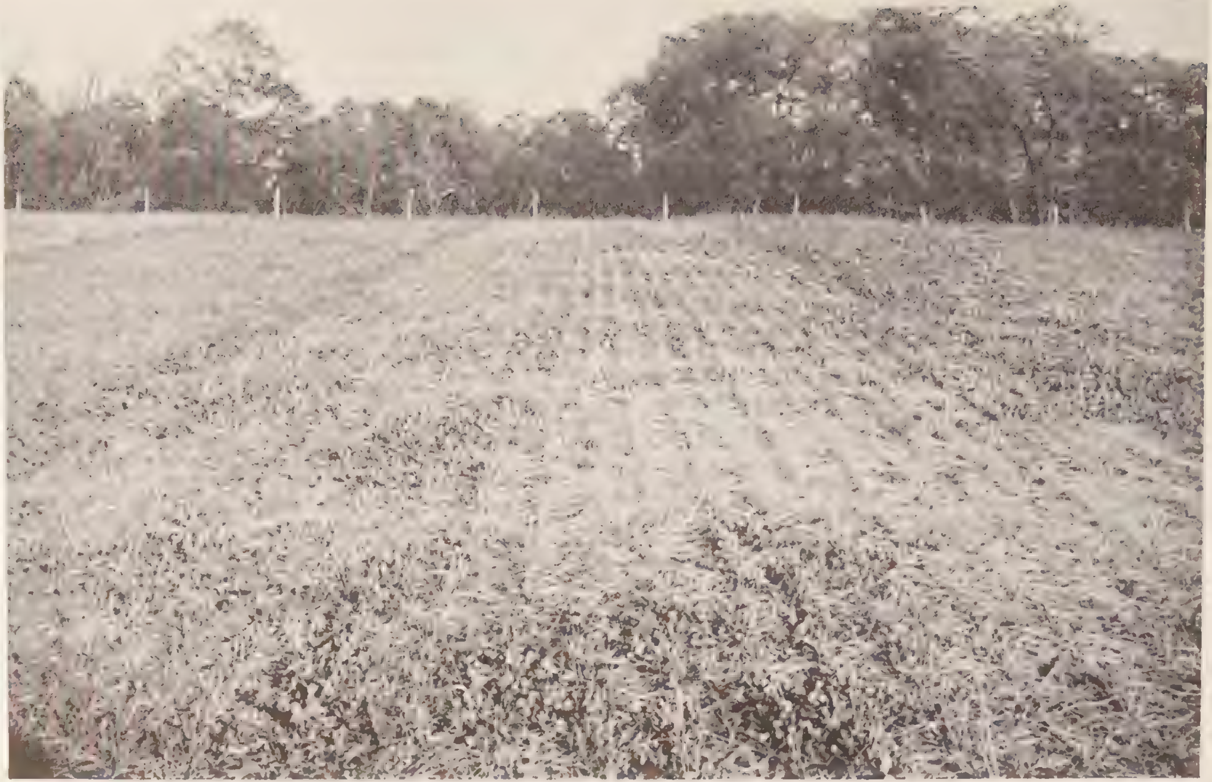

FIGURE IV.—CLOVER ON UNLIMED LAND

Fertilized with superphosphate and muriate of potash. Observe the small clover plants between the rows of stubble, and compare with Figure V, showing the limed end of the same plot, both pictures having been taken at the same time from the middle of the plot, by merely turning the camera.

provision was made for its use in the fertility experiments planned for the new location of the Ohio station. This was probably fortunate, as when liming became imperative the work was laid out on a more comprehensive plan than would have been adopted at an earlier date.

Up to about this period red clover had been grown as successfully in eastern as in western Ohio, but during the last decade of the century it became more and more uncertain, giving good yields in some seasons and on new land or on small areas in old fields, but giving way to larger and larger areas of sorrel and other weeds from season to season.

The experiments with fertilizers and manure on crops grown in rotation had been arranged on five tracts of land, each containing a little more than three acres, and subdivided into 30 tenth-acre plots, 16½ rods long. In 1900 the west half of the tract that was to be planted to corn was dressed with quicklime, spread over fertilized and unfertilized land alike at the rate of one ton per acre. This was continued until each of the five tracts had been similarly treated, when ground limestone, two tons per acre, was substituted for the quicklime and the liming was transferred to the east sides of the tracts, in order to make sure that any differences found were not due to natural differences in soil.

The effect of this first liming on the corn, oats and wheat, as they came in turn under observation, was so small—and faith was so weak—that these crops were not weighed separately; but when the clover came upon the land in its turn there was no mistaking the fact that the liming was producing a decided effect on that crop. The liming was then returned to the west sides of the tracts and has been continued there since. This liming of the east sides of three of the tracts has somewhat obscured the effect of the treatment, when the yields of the five tracts are averaged together, as is done in the following tables, making the gain for liming appear smaller than it actually has been.

In 1895 the work of the Ohio Station was extended to Strongsville, Cuyahoga County, and in 1902 the experiment described on page 136 was begun. In 1905 the work was further extended to two farms in southern Ohio located at Germantown, Montgomery County, and at Carpenter, Meigs

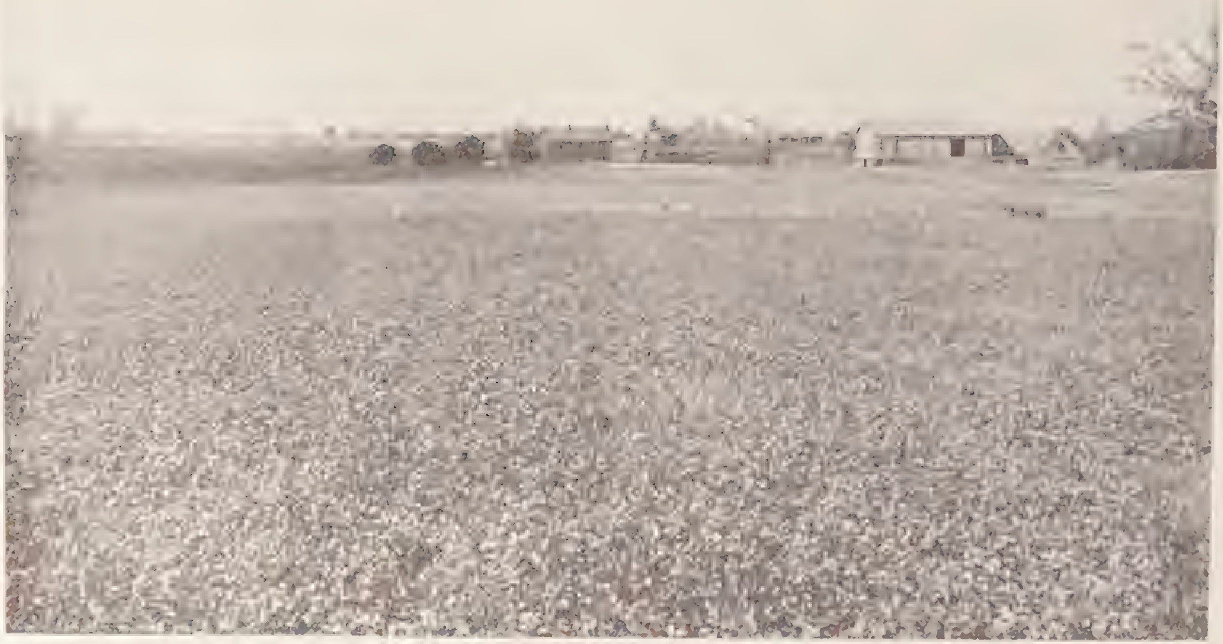

FIGURE V.—CLOVER ON LIMED LAND

In the Ohio Station's 5 year rotation at Wooster. Observe that the wheat stubbles are completely hidden. Compare with Figure IV, showing the unlimed end of the same plot. Both ends have received the same fertilizers and same treatment in every respect except that the west end has been dressed with powdered limestone at an average rate of about 2 tons per acre every 5 years, the limestone being stirred into the surface when preparing the land for corn, thus applying it 2 years before sowing the clover seed.

County. From 1910 to 1915 county experiment farms were established in 10 counties, widely scattered over the State, on most of which experiments are summarized to 1926 in Table V, which shows the increase due to liming in excess of the yields produced by other treatments.

In each of these treatments the same quantity of each fertilizing material is used throughout, whether used singly or in combination. The chemical fertilizers are distributed between the grain crops, and the manure is divided between the corn and wheat in the five-year and four-year rotations and is all applied to the corn in the three-year rotations.

In Table V the rates of application of manure and limestone are computed per acre per annum, although the manure has been applied only to the corn and wheat and the limestone only to corn in each rotation. In other words, the actual dressings in the five-year rotation in Wayne County have been two tons of limestone every five years on corn, and eight tons or four tons of manure each on corn and wheat for each five-year period. The hay crops have received no direct treatment. The limestone has been that known as fine limestone.

The contrast in lime requirement between eastern and western Ohio is very evident. In no case has the return for limestone, applied at rates equivalent to half a ton or less annually, been less than $9 per ton of limestone in eastern Ohio, except when slag phosphate was substituted for superphosphate in the basic treatment, and in this case the yield from the combination of superphosphate and limestone has been worth $4 per acre annually more than that from the slag phosphate without limestone, or enough to have paid twice over for the liming.

In western Ohio the return for liming has exceeded $9 per ton of limestone in but one case, and that where limestone has been used alone and in very small quantity. But the total value of the yield receiving this treatment—one ton of limestone every three years—has been $5 less for the three-year period than from that following a dressing of five tons of manure, and $28 less than that from a chemical fertilizer made up of superphosphate, muriate of potash and

TABLE V.—EFFECT OF LIMING OHIO SOILS: BASIC TREATMENT AND VALUE PER ACRE PER ANNUM AND PER TON OF LIMESTONE OF INCREASE DUE TO LIMING

COUNTY	Duration of test yrs.	Crops in rotation[9]	Basic treatment per acre per annum				Limestone per acre per annum lb.	Value of increase	
			Superphosphate lb.[10]	Muriate potash lb.	Nitrate soda lb.	Yard manure tons		Annual per acre dol	Per ton limestone dol.
			Eastern Ohio						
Wayne	22	C.O.W.Cl.T.	...	..	..	..	800	4.98	12.46
			84	52	48	..	800	5.40	13.50
			84	52	..[11]	..	800	7.34	18.35
			...	..	..	3.2	800	4.11	10.28
	20	C.O.Cl.	107	13	..	..	600	4.75	15.70
			...	..	..	2.7	600	4.32	14.40
	12	C.O.W.Cl.	80	..	..	2.0	1,000	5.61	11.23
			80	..	..	2.0	2,000	7.21	7.21
Cuyahoga	20	C.O.Cl.	107	53	53	..	667	4.95	14.84
			107	53	53	..	1,333	6.24	9.35
			107	..	..	2.7	1,000	3.25	6.50
			...	..	..	2.7	1,000	5.86	11.70
Trumbull	11	C.O.W.Cl.	120	..	..	2.0	1,000	4.74	9.48
Belmont	10	C.W.Cl.T.	150	12	30	..	1,000	7.43	14.85
Washington	12	C.S.W.Cl.	125	22	53	..	500	4.30	17.44
			200	..	..	1.3[12]	500	3.58	14.32
			Western Ohio						
Paulding	15	C.O.W.Cl.	125	22	53	..	1,000	—4.86	—2.43
Hancock	13	C.O.W.Cl.	90	15	40	..	500	1.71	6.84
Miami	16	C.O.W.Cl.	125	22	53	..	1,000	1.14	2.28
		C.C.O.Cl.	125	22	53	..	1,000	1.51	3.02
Montgomery	23	C.W.Cl.	67	..	..	1.7	333	1.06	3.18
	15		...	..	..	..	333	3.21	9.64
Hamilton	14	C.S.W.Cl.	80	..	..	2.0	1,000	2.16	4.32
Clermont	13	C.S.W.Cl.	125	22	53	..	1,000	4.01	8.02
			125[13]	22	53	..	1,000	3.48	6.96
			80	..	..	2.0	1,000	3.79	7.59
			80[13]	..	..	2.0	1,000	2.38	4.75

[9] C—corn; O—oats; W—wheat; Cl—clover; T—timothy; S—soybeans.

[10] 16 percent; [11] Sulphate of ammonia; [12] Sheep manure; [13] Undrained land.

nitrate of soda and costing $12 for the three-year period, both treatments being on unlimed land.

The Clermont County land has shown a greater increase from liming than any other western Ohio soil that has come under the investigation of the Experiment Station. In this test about 30 percent of the combined increase from chemicals and limestone, and about 20 percent of that from manure and limestone has been due to the limestone. In both these tests, therefore, liming has been of secondary importance, as compared with the use of fertilizers or manure, whereas in the eastern counties it is becoming impossible to produce full crops without the aid of lime, thus giving lime the position of first importance.

This does not mean, however, that the time will never come when liming may be as necessary to western, as it now is in eastern Ohio. Eastern Ohio soils have not always been as hungry for lime as they now are. Toward the close of the last century the farmers in this region began removing their rail fences, and for many years the land which these fences had occupied could be distinguished by its superior growth of clover, showing that the virgin soil had contained much more lime than that now found, and it is probable that a similar depletion of the lime supply will be experienced in the western counties. A bank deposit of $10,000 will honor a great many more ten dollar checks than one of $1,000, but the time will come when even the larger deposit will be exhausted, if it be continuously drawn upon without replenishment.

The outcome in Montgomery County strongly suggests that for these western Ohio soils a much smaller application of limestone than two tons per acre every third or fourth year would satisfy their present demands for lime and might return a profit on the lower cost of treatment.

There has been a large increase in the demand of the Wooster soil for lime during the 25 years of the test, as shown by the next table, which gives the value of the increase due to two tons of limestone on the otherwise unfertilized land by five-year periods, computing corn with its stover at 80 cents a bushel, oats and wheat with their straws at 50 cents and $1.25 a bushel, respectively, and hay at $12.00 a ton.

TABLE VI.—INCREASE DUE TO LIMING BY SUCCESSIVE PERIODS IN FIVE-YEAR ROTATION AT WOOSTER

1904-1908	1909-1913	1914-1918	1919-1923	1924-1928
$15.89	$14.38 [14]	$28.28	$38.47	$53.11

Indiana—The Indiana Experiment Station operates experiment farms in Tippecanoe and Huntington counties, in the northwestern and northeastern quarters of the State, the soils of both farms belonging to the Miami series. On neither of these farms has liming as yet produced any material increase in yield.

In southern Indiana the Station operates several experiment fields, all lying on or south of the latitude of Cincinnati, and on soils similar in general character to those of extreme southern Ohio and southern Illinois. The effect of liming these soils is shown in Table VII.

TABLE VII.—EFFECT OF LIMING SOUTHERN INDIANA SOILS [15]

NAME AND LOCATION OF FIELD	*Soil*	*Duration of test Years*	*Total limestone applied per acre Tons*	*Value of increase per ton of limestone Dol.*
Scottsburg, Scott Co.	Yellow clay	16	2.5	17.10
Jennings Co.	Clermont silt Loam	5	3	11.50
Moses Fell, Bedford Co.	Residual limestone	9	3	8.54
Worthington, Green Co.	Clay silt loam	11	4	12.10
Francisco, Gibson Co.	Residual sandstone	9	3	16.50

Scott, Jennings and Bedford counties lie east of the Indiana coal field; Scott and Jennings within the Illinois glaciation and Bedford within an unglaciated area bounded approximately by lines drawn from Bloomington southeasterly to New Albany on the Ohio River and southwesterly to Vincennes on the Wabash. Greene and Gibson counties are within the coal field, Greene on the border of and Gibson south of the southern limit of glaciation.

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[14] This slight reduction is due to transfer of liming during this period.

[15] Computed from summary reports and Circular 135, Purdue University Ag. Exp. Sta.

All the southern fields are covered with the blanket of loess which extends over the larger part of the Mississippi Valley, reaching a thickness of several feet in many places. The dust from a road ballasted with limestone has been found materially to affect the growth of clover on lime-hungry soils for several rods to the leeward; but if this dust has been swept from areas deficient in lime it is easy to understand that a deposit two or three feet in thickness may form a soil having the same deficiency, even though it lies immediately upon limestone.

The Indiana Experiment Station has estimated that three-fourths of the cultivated land in that State is acid; that about one-fourth is so very acid that clover will fail almost every year, and that on another fourth it will fail whenever the conditions are at all unfavorable, and that only about one-third of the State is sufficiently supplied with lime to make clover a reliable crop.[16]

Kentucky—The Illinoian glaciation extended over a small area in Kentucky opposite Cincinnati. Excepting this region, and the areas in which rivers or wind have taken part in the soil formation, the soils of the State have been derived from the underlying rocks, and therefore have been subjected to far longer periods of leaching than those whose formation has been due to glacial action.

Throughout north-central Kentucky the surface rocks are limestone, chiefly of the Cincinnati series, but within an area of several hundred square miles around Lexington the lower Trenton limestone becomes the surface, and the weathering of its upper, phosphatic layer has produced the remarkably fertile soil of the "Blue Grass" region.

In eastern and southeastern Kentucky is an extension of the mountainous Appalachian coal field; in the western part of the State is another coal field, surrounded on the east, south and west by a belt of St. Louis limestone, and at the extreme western end the soil is derived from the beds of gravel and sand deposited while the Gulf of Mexico

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[16] Purdue Univ. Ag. Exp. Sta. Bul. 213.

TABLE VIII.—EFFECT OF LIMING KENTUCKY SOILS[18]

STATION	Duration of test	Location and Soil Basis	Annual value of manured yield	Value of increase	
				Annual per acre	Per ton limestone
	yrs.		Dol.	Dol.	Dol.
Berea	13	Eastern, shale	16.98	5.68	18.46
Fariston	10	Eastern coal field, shale and sandstone	6.59[19]	4.38	10.95
Greenville	10	Western coal field, sandstone	13.46	3.27	8.17
Russellville	11	Western, St. Louis limestone	16.67	5.06	13.90
Lone Oak	13	Western, Terrace gravels and loess	18.81	3.32	10.80
Mayfield	12	Western, Terrace gravels and loess	15.94	7.45	22.35

[18] Computed from Bul. 272, Kentucky Agr. Exp. Sta. [19] Unmanured.

There does not seem to be any definite relation between the geologic origin of these soils and their response to liming. They are all residual soils that were subjected to leaching during the countless ages when the soils of northern Ohio, Indiana and Illinois were covered with ice, while the loessal blanket that covered the southern ends of these states probably extended over most of the Kentucky fields under consideration.

The most famous of the Kentucky soils, that of the Bluegrass region, is not included in Table IX, for the reason that it has thus far shown no response to liming, although it is stated that it is sometimes necessary to add lime in farm practice in order to get a stand of clover.

was receding from the junction of the Ohio and Mississippi rivers.

The Kentucky Experiment Station is located at Lexington. The response to lime on this soil has thus far been too irregular to justify its use. Several experiment fields are being operated in other parts of the State, the general plan of treatment on which is first to use manure or crop residues on the land, and to add powdered limestone to this treatment until a total of four tons per acre of limestone has been used, after which the liming has been discontinued.

In Table VIII is shown the value of the average manured yields in these tests, the value of the increase due to liming, in excess of the yields produced by the manure and residues, computed per acre per annum and per ton of limestone, using the valuations hereinbefore employed, except that soybean hay is computed at $18 a ton,[17] the rotation being corn, soybeans, wheat and clover.

Illinois—Approximately three-fourths of Illinois rests upon the coal measures, with their alternating layers of shales, sandstones and limestones; the Silurian and Devonian limestones which underlie the coal being the surface rocks only in the northern and northeastern quarter of the State.

Three periods of glaciation are recognized in the State. As mapped in Bulletin 123 of the Illinois Experiment Station, the old Illinoian glaciation, which occurs only in the southern tier of counties in Ohio, covers about fifty counties in western and southern Illinois; the Wisconsin, the major glaciation in Ohio, spreads over about thirty counties in northeastern Illinois, and the Iowan, intermediate in time between the other two, covers half a dozen counties in the northern end. Only three small areas were not visited by the glaciers—Jo Daviess, the extreme northwestern county of the State; Calhoun and part of Pike, between the Illinois and Mississippi Rivers, and seven counties in the southern end of the State.

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[17] In the average Ohio experiments 160 pounds of soybean hay has carried a bushel of beans, and the beans have been computed at $1.50 per bushel. This is practically equivalent to computing the hay at $18 a ton. This may seem high, but the object is to make all the tests as nearly comparable as possible.

TABLE IX.—ILLINOIS FERTILITY TESTS—RESULTS SUMMARIZED TO 1925 IN VALUES PER ACRE FOR FOUR-YEAR ROTATION

STATION	*Glaciation*	*Duration of test yrs.*	*Live-stock farming*				*Grain farming*				
			Basic yield Dol.	*Increase* [19] *from*			*Basic yield Dol.*	*Increase* [19] *from*			
				Manure Dol.	*Lime Dol.*	*Phosphate Dol.*		*Residues Dol.*	*Lime Dol.*	*Phosphate Dol.*	*Kainit Dol.*
			Northern and northeastern Illinois: Brown to black soils								
LaMoille	Wisconsin	13	143	25	—1.75	1.40	111	14	3.63	2.89	—2.62
Joliet	Wisconsin	14	90	23	4.15	19.27	79	7	8.53	21.21	7.84
Spring Valley	Wisconsin	10	124	15	2.00	12.96	126	12	7.67	2.73	—6.11
Minonk	Wisconsin	14	137	16	—1.95	3.46	111	12	—.80	2.46	—2.68
Sidell	Wisconsin	13	127	9	—4.84	4.79	89	3	3.42	6.71	.78
Average			124	18	—.47	8.38	103	10	1.49	7.20	—.56
			Northwestern Illinois: Brown soils								
Mt. Morris	Iowan	13	118	27	16.79	.74	93	9	22.43	7.05	4.49
Dixon	Iowan	14	98	37	12.66	8.67	87	11	10.67	9.00	3.60
Aledo	Upper Ill.	14	134	25	7.92	2.50	113	4	11.23	7.14	2.05
Kewanee	Upper Ill.	9	130	23	6.50	8.44	108	4	11.17	12.82	1.70
Average			120	28	10.97	5.09	100	7	13.87	9.00	2.96
			Middle Western Illinois: Gray-brown soils								
Carthage	Illinoian	13	94	17	17.41	8.54	71	16	23.26	3.92	5.27
Clayton	Illinoian	13	88	13	32.28	5.55	69	15	12.28	5.78	11.14
Carlinville	Illinoian	15	73	23	30.00	1.17	64	3	21.27	6.39	2.84
Pana	Illinoian	10	79	7	18.13	4.91	59	10	20.31	5.22	—1.84
Lebanon	Illinoian	14	90	21	13.57	1.47	69	9	20.79	—.83	3.42
Average			85	16	22.28	4.33	66	11	19.58	4.10	4.17
			Southeastern Illinois: Gray silt loam on tight clay								
Toledo	Lower Ill.	12	40	10	42.29	5.00	31	4	30.11	6.95	12.94
Oblong	Lower Ill.	13	39	20	31.44	10.39	40	8	23.79	11.10	5.94
Enfield	Lower Ill.	12	24	12	41.44	2.63	34	6	30.63	9.38	4.14
Ewing	Lower Ill.	15	19	14	46.35	7.77	20	1	38.55	3.48	19.87
Raleigh	Lower Ill.	15	28	18	41.82	5.89	28	6	32.48	6.69	8.74
Average			31	15	40.67	6.34	31	5	31.11	7.52	10.33

[19] The increases are for manure alone or for residues alone in excess of the basic yields; for limestone, in excess of the increases due to manure or residues; for raw phosphate, in excess of the yields due to manure or residues and limestone combined; and for kainit, in excess of the yields due to the combination of manure or residues, limestone and raw phosphate. The valuations employed are 80 cents a bushel for corn, 50 cents for oats, $1.25 for wheat and $12.00 a ton for hay, no account being taken of stover or straw.

Following the glacial epoch, the major part of the State was covered with a loessal blanket, reaching a thickness of many feet along the Mississippi River and in other places, and thus modifying or totally obscuring the effect of the underlying rocks.

The Illinois Experiment Station operates a large number of outlying experiment fields, so distributed over the State as to include its principal soil types and the entire range of its climatic conditions.

On many of these fields the treatment has been designed to represent two different types of farming, one in which the produce of the land, excepting the wheat grain, is fed to livestock and the resultant manure is returned to the land, and one in which only the grains are removed and the residues—clover, straws and stover—are plowed under without any manure.

In both systems the manured land and that on which the residues are plowed under have received ground limestone, applied once in each rotation, usually at the rate of four tons per acre for the first rotation and two tons per acre subsequently, and spread over the surface in the preparation of the land for wheat. The rotation has been corn, oats, clover and wheat, grown in the order named, with sweet clover sown in the wheat to be plowed down for the corn. The liming was generally discontinued in 1922.

The crops are not actually fed in these experiments, but a quantity of manure equal to the total weight of crop produced during the previous rotation has been applied to the succeeding corn crop.

In Table IX, compiled from Bulletins 273 and 280 of the Illinois Station, is shown, for the periods beginning with the full treatment in each test and ending with 1925, the average value for each four-year rotation of the crops grown on the untreated land in nineteen of the experiment fields that have been treated in conformity with the plan above outlined, the fields being grouped with reference to the prevailing color of their soils, their location on the glacial map of the State and their reaction to limestone.

The lower values of the basic yields on the grain farming side of the table are due to the fact that the clover crop, having been plowed under, cannot be included in computing the value of the produce. This difference has amounted to about $20 per rotation, except on the southeastern soils, on which the clover has usually refused to grow without the help of lime.

If we compute the cost of liming at $5 a ton of limestone, spread on the land, no field within the Wisconsin glaciation has returned sufficient increase from liming to justify the cost; the average effect of the liming being nil on the manured land and not half enough to pay its cost on the land receiving the crop residues.

On the older glaciations liming has produced a profitable increase, excepting on the manured land in the Aledo and Kewanee fields, which are located but a few miles south of the limit assumed for the Iowan glaciation, the effect of the liming increasing rapidly as we go southward, until on the thin, gray soils of the southern fields the increase due to liming has been equal to or greater than the basic yields.

The superior effect of liming on the manured land in these southern fields has been due to the clover, as shown by Table X, which gives the increase on these fields for manure and limestone, in excess of that for manure alone, and the relative values of the increase for the different crops, computed for the four years of the rotation period.

Table X.—Increase for Manure and Limestone in Excess of that for Manure Alone in Southeastern Illinois Experiment Fields

	Toledo	*Oblong*	*Enfield*	*Ewing*	*Raleigh*	*Average*
			Increase per acre			
Wheat, Bu.	11.6	7.7	11.3	12.7	13.1	11.3
Corn, Bu.	10.5	11.7	12.6	15.5	13.7	12.8
Oats, Bu.	12.0	9.6	10.0	13.3	9.4	10.9
Hay, Cwt.	22.2	12.8	20.4	19.0	16.4	18.2
			Value of increase			
Wheat, Dol.	14.50	9.60	14.12	15.90	16.37	14.10
Corn, Dol.	8.40	9.36	10.08	12.40	10.96	10.24
Oats, Dol.	6.00	4.80	5.00	6.65	4.70	5.45
Hay, Dol.	13.32	7.68	12.24	11.40	9.84	10.92
Total	42.22	31.44	41.44	46.35	41.87	40.71

The wheat receives the liming, and gives the largest value in the increase, at the prices here assumed. The corn follows the wheat in these rotations, and stands second in the value of its response to liming in two of the tests, while clover, the last crop in the series, stands second in the other three, and gives more than one-fourth of the average value of the increase. Of course, a different scale of prices might alter these relative positions, but under any reasonable valuation clover would remain a very important factor in computing the effect of the liming, and it would seem that, unless the value here assumed for clover hay is much greater than can be realized from feeding or selling it, it has been an expensive fertilizer.

III.—TRANS-MISSISSIPPI SOILS

Iowa—The soils of Iowa have been under cultivation for a comparatively short time, and it is only within a very recent period that the Iowa farmer has begun to realize that the fertility of his land is not inexhaustible. Since 1912 the Iowa Experiment Station has so extended its work as to include the study of the soils of the State as a whole, at first through laboratory investigation and later through field tests, widely scattered over the State, with the result that many soils have been found to be ready to respond to lime as well as to other fertilizing materials. A recent bulletin of that Station[20] reports the outcome of field experiments made during 1915 to 1919 in eight different counties in which the yields per acre produced by manure and lime were increased over those given by manure alone by four to ten bushels of corn, five to twelve bushels of oats and one-sixth to one-third of a ton of clover hay.

The later glaciations pushed southeastward through central Iowa, covering nearly half the State, but east, south and west of this area is a belt, one to four counties in width, which the ice sheet did not reach and which is covered with loess. There are places in the State where a black, loessal soil two or three feet in thickness overlies a yellow clay that has evidently been derived from the breaking down of limestone, but the lime has been so completely leached out of the loessal covering that it is necessary to add lime to get a satisfactory stand of alfalfa or sweet clover.

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[20] Iowa Exp. Sta. Bul. 150, Revised popular edition.

Missouri—In addition to field experiments, conducted on a few typical soils of the State, the Missouri Experiment Station has made a large number of laboratory tests. As a result of nearly 2,000 such tests, made in 1920 and 1921, on soil samples sent in from 96 counties, the conclusion is reached that no single type of soil in the State is entirely free from acid, while some types are characterized by high acidity. The more level upland soils generally show the higher lime requirement, while on the lowlands and rolling uplands less lime is needed. The variation in need for lime, as indicated by the test, corresponds closely with the growth of the leguminous crops, although it is found that clover or alfalfa will often thrive on one soil with a given lime requirement but will fail to grow on another showing the same degrees of acidity according to the laboratory test. The difference in these cases is usually due to difference in supply of organic matter and the resultant fertility.[21]

CONCLUSIONS

These experiments show that soils lying over sandstone or shales are generally in need of lime, and that the time eventually comes when such soils cannot be made to produce full crops until lime is added; but that where the soil is derived from limestones it is only when the land has been a very long time under cultivation, or where the effect of the limestone is obscured by a deep covering of loess, that liming is likely to be profitable.

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[21] Mo. Exp. Sta. Bul. 189, p. 62.

X

Practical Problems in Liming the Land

Carriers of lime—In earlier days, before the practice of grinding lime came in vogue, it was customary to distribute freshly burnt lump lime over the plowed field in small piles, so situated that the ground between could be covered by shoveling. The lime was sprinkled with water and covered with loose earth, and after it had slaked it was mixed with earth and spread with a shovel. This method is unsatisfactory in that it is impossible to spread the lime uniformly by hand. Some spots will get too much and others not enough.

Lime intended for building purposes is now usually ground into a powder at the point of manufacture, so that it may be handled in sacks. When quicklime is handled in this way it is necessary to exercise great care to keep the lime dry, as it absorbs moisture very readily and this causes the lime to swell and burst the sacks.

Hydrated lime—Builders slake their lime before using it, by wetting it to a paste. For some purposes this paste must be made several days before using it, in order to secure a thorough slaking of the lime. Many of the lime manufacturers are now slaking the lime at their works, after which it is dried and ground and sold in sacks. Lime so prepared is called "hydrated," from the Greek "hydros," water. In the process of hydrating the lime enters into combination with about one-third its weight of water, 2,000 pounds of quicklime carrying the same quantity of calcium as 2,640 pounds of hydrated lime. This hydrated lime is still a dry powder, the water being chemically combined with the lime as it is in many air-dry substances, and by application of heat it may be driven off again, the lime returning to its original condition of quicklime.

Carbonate of lime—When quicklime is exposed to the air it soon absorbs moisture and becomes "air-slaked," or hydrated, and on longer exposure it combines with the carbon dioxide which is always present in the atmosphere and slowly reverts to the original condition of carbonate of lime in which it was found in the quarry. One hundred pounds of pure carbonate of lime contains 56 pounds of calcium oxide, or quicklime, and 44 pounds of carbon dioxide; limestone is carbonate of lime, combined with water and some impurities, so that it requires about two tons of limestone to carry as much calcium as would be found in one ton of quicklime burnt from the same stone.

Magnesian lime—Most limestones contain more or less magnesium, the proportion of magnesium carbonate reaching 46 percent, combined with 54 percent of calcium carbonate in pure samples of the rock known as Dolomite. This is a hard, blue limestone, distinguished from ordinary limestone by its darker color and greater density and weight. It does not effervesce so readily when treated with dilute hydrochloric acid as does calcium limestone.

Magnesium carbonate neutralizes acidity quite as effectively as does calcium carbonate, but the salts of magnesium become injurious to plants in smaller quantity than do those of calcium. While this is true of the chemical salts of magnesium, such as magnesium sulphate or a pure magnesium oxide, the amount of magnesium that would be given to the land in an ordinary dressing of raw magnesian limestone will cause only benefit and not injury on ordinary soils.

The calcium-magnesium ratio—Investigations by O. Loew and others, made chiefly in Japan and by pot cultures, have been interpreted as indicating the importance of a certain ratio between the calcium and magnesium of the soil; the conclusions being that in general calcium should be in excess of magnesium, although for some crops a ratio of 1 to 1 was found most effective. While further investigation along this line is needed the results of field experiment support the use of magnesian limestone for the improvement of ordinary soils.

In an experiment that has been running 13 years at the Ohio Experiment Station a dolomite from western Ohio, analyzing about 54 percent calcium carbonate and 43 percent magnesium carbonate, has been compared with a limestone analyzing about 85 percent calcium carbonate and 5 percent magnesium carbonate with the results shown in Table XI, the liming materials being applied to corn, in a four-year rotation of corn, oats, wheat and clover.

TABLE XI.—COMPARISON OF MAGNESIAN AND NON-MAGNESIAN LIMESTONES

PLOT No.	*Liming materials per acre*	*Value of increase per rotation*[1]
14	Limestone, magnesian, 2 tons	$25.00
17	Limestone, non-magnesian, 2 tons	25.08
15	Hydrated lime, magnesian, 1½ ton	26.48
18	Hydrated lime, non-magnesian, 1½ ton	26.68

These differences between magnesian and non-magnesian lime are too small to have any significance. The soil is a silt loam, containing a slightly larger percentage of magnesium than of calcium.

This conclusion, that there is little practical difference between the effect of the ordinary limestones of the country due to differences in proportion of calcium to magnesium, is supported by field experiments reported by Lipman and Blair of the New Jersey Experiment Station,[2] and by the Illinois Experiment Station.[3]

Laboratory tests, reported by M. F. Morgan and R. M. Salter, at the Ohio State University,[4] indicate that fineness of grinding may be more important with the harder dolomitic limestones than with the softer, high calcium stones.

Comparisons of quicklime and ground limestone—At the Pennsylvania State College Experiment Station quicklime has been applied at the rate of two tons per acre to every corn crop in the four-year rotation of corn, oats, wheat and clover, not only on unfertilized land but also on land receiving six tons of manure per acre on each corn and wheat crop, and ground limestone has been used on other-

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[1] Computing corn at 80 cents a bushel, oats at 50 cents, wheat at $1.25 and hay at $12.00 a ton, stover and straw being included with the grains.

[2] Soil Sci. 15(1923) No. 4, pp. 307-328.

[3] Ill. Exp. Sta. Ann. Rpt. 1925-26, p. 19.

[4] Soil Sci. 15 (1923) pp. 293-305.

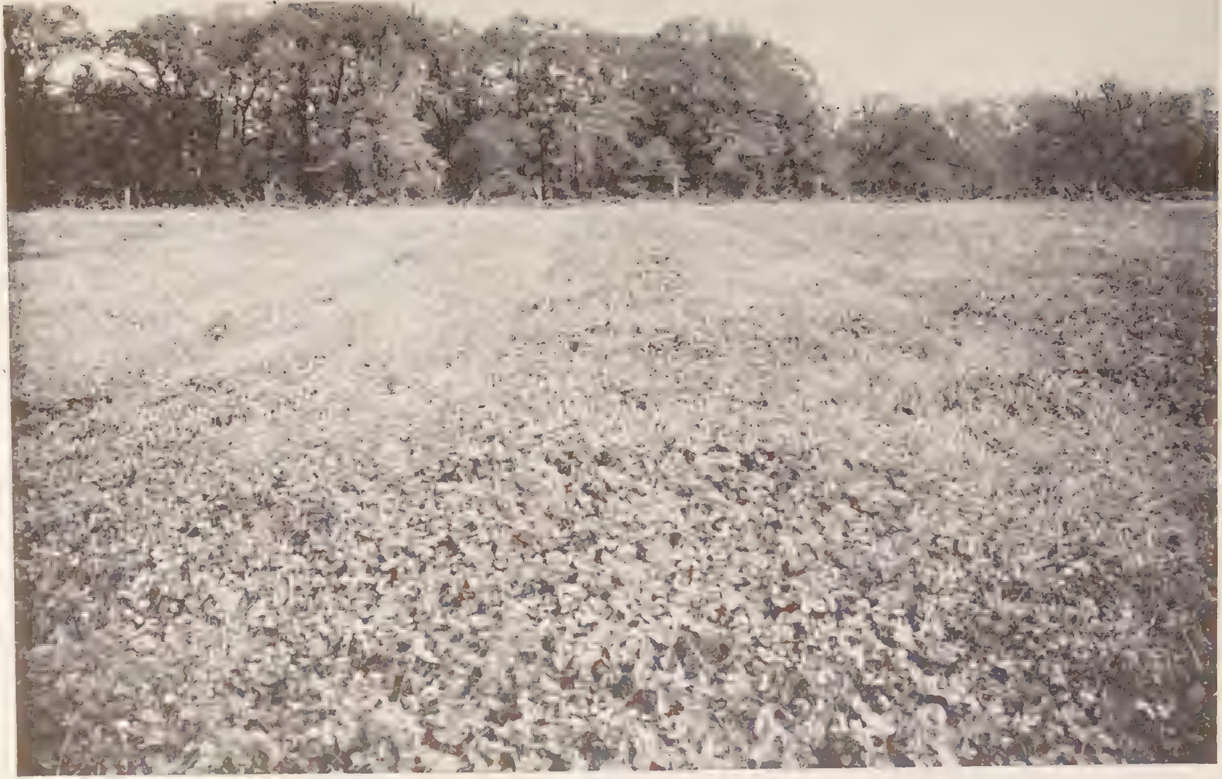

FIGURE VI.—CLOVER ON MANURED LAND, UNLIMED

In the Ohio Experiment Station's 5 year rotation at Wooster. This plot has received two dressings of barnyard manure every 5 years, one on corn and one on wheat, the manure being applied at the rate of 8 tons per acre on each crop. Observe that while there is much more clover on this plot than on Plot 8 (Figure IV) where chemical fertilizers have been used, it is still a very weak and irregular stand. Compare with Figure VII, showing the limed west end of the same plot, both pictures being taken at the same time.

wise untreated land at the rate of two tons per acre on corn and wheat, thus giving two tons per acre of quicklime or four tons of limestone, or approximately equal quantities of calcium, for each four-year period. The outcome indicates that in the 40-year average it has made little difference which carrier of lime was used.

In 1905 an experiment was begun on the Wooster farm of the Ohio Experiment Station, designed to compare different kinds and quantities of liming materials in a rotation of corn, oats and clover. The land had been kept in good condition up to the beginning of the test, and for several years the effect of the treatment was relatively small, but during later years the clover crops became very poor, finally failing altogether in 1919, apparently because of a combination of lime deficiency and disease, and sweet clover was substituted for the medium red in 1921. The result has been that, wherever lime is used good crops of sweet clover are harvested, but it has refused to grow on unlimed land, even though liberally manured or fertilized.

On part of the land quicklime and ground limestone have been used alone, and on part quicklime, air-slaked lime, hydrated lime and ground limestone have been used over a basic dressing of yard.manure, eight tons per acre, the treatment being all given to the corn.

In Table XII is shown for this test the 21 years' average increase produced by the liming, in excess of that due to the manure and fertilizing materials, and the value of this increase, computed on the prices used in Table X.

TABLE XII.—CARRIERS OF LIME:
VALUE OF INCREASE DUE TO LIMING IN CORN—OATS—CLOVER ROTATION, COMPUTED PER ACRE PER ROTATION

PLOT	*Basic treatment*	*Carrier of lime*	*Value of increase*
2	Yard manure	Quicklime, 500 lb.	$9.20
3	Yard manure	Quicklime, 1,000 lb.	11.40
5	Yard manure	Quicklime, 2,000 lb.	18.00
6	Yard manure	Limestone, 1,780 lb.	13.00
8	Yard manure	Air slaked lime, 1,780 lb.	19.20
9	Yard manure	Hydrated lime, 1,320 lb.	16.30
14	None	Quicklime, 1,000 lb.	19.20
15	None	Limestone, 1,780 lb.	14.10

The liming materials have been used in this test on the assumption that 1,000 pounds of quicklime, 1,320 pounds of hydrated lime and 1,780 pounds of limestone should produce practically the same neutralizing effect on soil acidity. The outcome indicates a better return for the hydrated lime and limestone on the manured land than for 1,000 pounds of quicklime. On land not receiving manure both quicklime and limestone have caused larger increases than on the manured land, an outcome corresponding to that in the experiment previously described, and explainable by the assumption that liming increases the nitrogen-fixing activities of the soil organisms and that manure not only furnishes nitrogen but also a little lime.

Some of these problems are being studied on the Trumbull County Experiment Farm, in a rotation of corn, oats, wheat and clover, which has been running for 11 years, with the outcome shown in Table XIII, which gives the increase for liming over a basic dressing of eight tons of stall manure reinforced with 480 pounds of superphosphate per acre per rotation:

TABLE XIII.—CARRIERS OF LIME AND PLACE OF LIMING IN THE ROTATION

Plot No.	*Treatment per acre*	*Value of increase Dol.*
15	Limestone, fine, 1 ton each on corn and wheat	18.30
17	Limestone, fine, 2 tons on wheat	12.00
20	Quicklime, 1 ton on corn	17.87
21	Quicklime, 1 ton on wheat	14.65
23	Hydrated lime, 1 ton on corn	20.60
24	Hydrated lime, 1 ton on wheat	17.58

In this test it has been definitely better to apply the liming to the corn than to the wheat, and one ton of hydrated lime has given a larger increase than one ton of quicklime or two tons of fine limestone.

Response of different crops to liming—Table XIV shows the increase in the different crops due to the liming, in excess of that produced by the different fertilizer treatments in the five-year rotation at Wooster, the increase being computed in percentage of the yield due to the basic treatment.

TABLE XIV.—EFFECT OF LIME ON CROPS GROWN IN ROTATION

	——Percentage increase for liming——					*Total*
BASIC TREATMENT	*Corn*	*Oats*	*Wheat*	*Clover*	*Tim.*	*produce*
0..None	45	20	25	60	38	29
2..Superphosphate	22	9	20	43	19	26
3..Muriate potash	45	20	32	39	20	35
5..Nitrate soda	31	20	24	43	34	27
6..Superphos., nitrate soda	10	3	12	38	9	18
8..Superphos., muriate potash	26	12	26	50	25	28
9..Muriate potash, nitrate soda	45	20	30	59	13	35
11..Superphos., mur. potash; nitrate soda	24	2	10	35	11	18
18..Yard manure [5]	12	3	12	21	35	16
20..Yard manure [6]	23	7	18	36	38	23
Average	28	12	21	42	24	25

Table XIV shows that there has been a considerable difference in the response of the different crops to liming, clover showing a much greater effect on the unfertilized land and in the average of all the treatments than any other crop, with corn next, while oats shows the lowest response and wheat and timothy considerably less than corn.

The liming has caused a much greater increase in the corn grain than in the stover, while the opposite effect has been produced with oats, and also with wheat, except where the fertilizer has carried either nitrogen, or both phosphorus and potassium.

The last column of the table shows that liming has added one-fourth to the total yield of the unlimed land in the average, the gain for liming being increased where the fertilizer contains muriate of potash and reduced where nitrate of soda and superphosphate are used in combination, and where manure is used, especially in the larger quantity; but neither manuring nor any fertilizer treatment has made liming unnecessary.

The excessive use of lime—Observing the beneficial effects of liming, farmers have sometimes used it in excessive quantities, and have neglected other measures for the maintenance of fertility. Lime is only one of the soil amendments which require our attention, and it will not take the place of any of the others.

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[5] Eight tons each on corn and wheat. [6] Four tons each on corn and wheat.

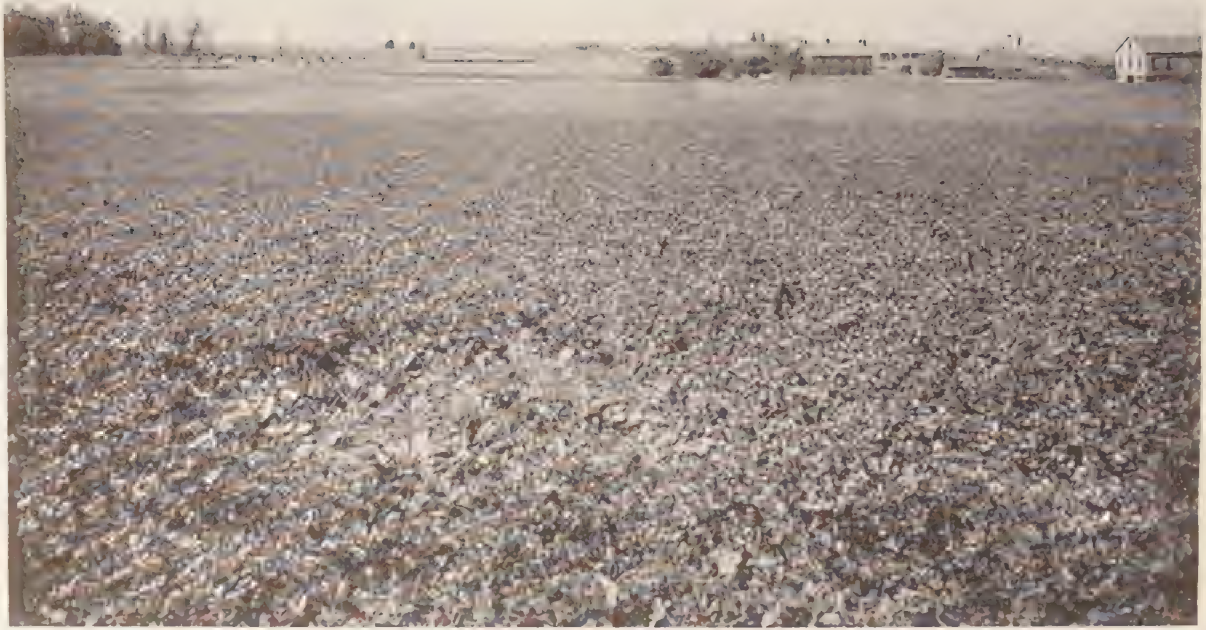

FIGURE VII.—CLOVER ON MANURED AND LIMED LAND

In the foreground is a spot where a wheat shock stood too long and killed out the clover. The plaintain, however, was not so easily killed. Compare with Figure VI, showing the unlimed end of the same plot.

In the earlier use of lime it was sometimes applied at the rate of 5 or 6 tons or more of quicklime per acre and the outcome was that there was at first a large increase in crop production, but the time came when the land failed to respond and the yield fell to a lower level than where no lime had been used, thus giving rise to the proverbs:

> "Lime and lime without manure
> Leaves both farm and farmer poor;"
>
> "Lime enriches the father but beggars the son."

This outcome has followed the use of burnt, or caustic lime. Carbonate of lime, in the form of chalk or decomposing limestone, may be used in large quantity without injury to the land. For example: Broadbalk Field, at the Rothamsted Station, is supposed to have received a dressing of probably 100 tons of chalk per acre, dug up from strata underlying the field and spread over the surface a century ago, the chalk being a soft limestone common in certain parts of England; but this field has shown a remarkable persistence in fertility. As stated on page 70, the investigations of the Ohio Experiment Station have shown that some of the native soils of the State contain lime to the equivalent of more than 100 tons of limestone per acre in the upper 6 inches, but these are fertile, river bottom lands, and the lime is carried in the coarse form of limestone sand.

The possibility of excessive use of lime is shown by two of the Ohio Station's experiments. On the Paulding County experiment farm refuse lime from the nearby beet-sugar factory, used at the rate of two tons per acre on sugar beets or corn, is distinctly injuring the clover grown in rotation. This lime is practically a hydrated lime partly reduced to the carbonate form by exposure.

This farm is located in the bed of ancient Lake Maumee and lies over limestone. It has been reclaimed from marshy conditions within recent years and its soil is naturally well supplied with lime.

In one of the liming experiments at Wooster fine limestone has been used on corn, in a rotation of corn, oats, wheat and clover, at rates of two tons, four tons and eight tons per acre for twelve years. At first the dressing of eight tons of limestone per acre produced a greater increase of crop than any smaller one, and the land became quite perceptibly darker in color, but during later years both corn and clover —the two crops most sensitive to lime deficiency—have given decreasing yields on this plot, and the value of the increase due to liming has been materially reduced, as shown by Table XV, which gives the total value of the increase by three four-year periods for the different applications.

TABLE XV.—EFFECT OF DIFFERENT RATES OF LIMING BY FOUR-YEAR PERIODS

	Rate of liming and value of increase		
PERIOD	*2 tons*	*4 tons*	*8 tons*
I	$15.90	$21.90	$25.40
II	20.97	26.30	26.15
III	30.83	39.00	18.16

Laboratory tests have shown that, while a slight alkalinity in the soil is essential to nitrification, this process is suspended when the alkalinity becomes excessive. This seems to be the explanation of the outcome shown on this soil which contains a large store of organic matter.

The burning out of organic matter by lime—The sterility that has followed the excessive use of quicklime has apparently been largely due to the exhaustion of the organic nitrogen of the soil. It would seem that the abundant supply of lime in the very finely divided form which results from burning and slaking stimulates an abnormal activity of the nitrifying bacteria, and that the nitrogen of the soil is liberated from its organic combinations and converted into nitrate more rapidly than the crops can utilize it, especially when the supply of available phosphorus and potassium is not maintained by fertilizing, and consequently the excess of nitrate is lost by leaching, and the time comes when the store of organic nitrogen is exhausted. That ground limestone does not ordinarily produce the same effect may be due in part to the fact that no machinery has been developed hitherto which will reduce the raw stone to the extremely fine powder secured by burning.

This explanation is supported by the first proverb quoted, which shows that experience has demonstrated that it is lime *without manure* that impoverishes the farm.[7]

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[7] See also the New Jersey experiments, quoted on page 83.

On the other hand, those countries in which the soil has been largely derived from limestones are proverbially fertile, but the weathering of a limestone into soil is a very slow process, requiring ages for its completion, and during the process there is in humid regions a constant dissolving out and carrying away of the lime carbonate, and consequently a steady increase in the relative proportions of silica and organic matter, so that the time never arrives when the natural accumulation of lime carbonate is excessive.

Causticity of quicklime—When quicklime comes in contact with moisture a chemical reaction takes place by which intense heat is developed, a fact of which use is sometimes made for the destruction of animal bodies or other organic matter. This heat is sufficient to stop bacterial action by killing the organisms concerned in it, and such tissues as escape complete oxidation in the burning will be preserved from decay. To accomplish this effect in the soil, however, the quicklime would have to be used in such quantity that the crop immediately following the application would be injured, and such a result has sometimes happened; but so long as the crops following the liming show increased yield we may be sure that the lime is performing a useful function in the soil, which will continue so long as the supply of the other elements necessary to bacterial action and plant growth is maintained.

The injury from quicklime has been due to its excessive use, and to the neglect of maintaining the supply of other necessary elements, not to any special quality of the quicklime; and when used in moderate quantity of not more than a ton to the acre once in four or five years, and on soils that are actually in need of lime, it is not at all probable that either the father or the son will suffer, provided only that it is remembered that liming is only one of the various forms of soil amendment that must be systematically followed if the farm is to be handed down to the son in a condition equal to that in which the father found it.

Whether to use quicklime or carbonate of lime, therefore, depends upon whether it costs more or less to spread one ton of quicklime or two tons of carbonate of lime on the field, taking into consideration the total quantity of calcium and magnesium contained, fineness of grinding, original cost, freight, hauling and spreading. It may often be the case that distance from railway station or condition of roads will decide the question one way or the other.

Because enough is good it does not follow that more is better, is a rule that applies to other soil treatments as well as to liming. There are no more effective carriers of nitrogen to the soil in ordinary use than nitrate of soda and sulphate of ammonia, yet it would be much easier to destroy the crop with either of these salts than with quicklime.[8] Common salt in small quantities is harmless to vegetation, if not sometimes beneficial, but a very little excess of salt is so destructive to ordinary plants that it is used as a weed killer.

Quicklime changes to carbonate in the soil—In whatever form lime is applied to the soil it very quickly reverts to the carbonate, if not originally given in that form. This may easily be demonstrated by the following simple

Experiment

> Place a small lump of quicklime in a saucer and sprinkle it with about one-third its weight of water. It will very quickly begin to swell, with the evolution of considerable heat, and will fall to a fine powder, occupying much more space than the original lump. This is hydrated lime. Put a spoonful of this powder into a tumbler-full of water, stir it thoroughly and let it settle until the liquid above the lime is clear. Pour off this clear liquid into another tumbler and breathe into it through a glass tube or a straw. A white cloud will immediately form, due to the combination of the dissolved lime with the carbon dioxide of the breath. This cloud is carbonate of lime—just the same substance as ground limestone, except that its particles are indefinitely smaller than any to which limestone can be reduced by grinding.

Deceptions practised in the sale of lime—Farmers have been familiar with lime in its burned form for centuries. They have used this lime on their fields in the older countries for an unknown period, first slaking it to a fine powder with water, and the term "slaked" lime was well understood. About the beginning of the present century the producers of lime began slaking it at the point of production, thus putting it in more convenient form for the builder, and for this product they borrowed the chemical term "hydrated" lime, hydrated meaning just the same thing as slaked. We slake our thirst with water—the "hydros" of the Greeks, and we slake the thirsty lime with water.

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[8] See Chapter XIX.

But the term "hydrated" was an unfamiliar one to the farmer, and it was seized upon by certain unscrupulous dealers as a cloak to cover a waste product of the hydration plants which was sold to the farmer at a price above the market price for pure lime, as possessing a special fertilizing value because it had been "hydrated."

Lime is used in certain manufacturing processes in which it is reduced to the carbonate form and becomes a waste product. Such lime has been sold at fancy prices because it was "carbonate" of lime, another chemical term with which farmers who did not know that common limestone is carbonate of lime were deceived.

Marl, such as that described on page 15, has been exploited as possessing some superior quality, whereas it is just the same carbonate of lime that common limestone is, except that it may be more finely divided than any but the finest limestone powder.

But no fineness of division will make a ton of carbonate of lime the equal of a ton of pure hydrated lime, nor a ton of hydrated lime the equal of a ton of pure quicklime in neutralizing power, for that is based wholly on the number of pounds of calcium, or of calcium and magnesium combined, contained in the ton. Following are the number of pounds of calcium that would be contained in one ton of each of the three forms of lime, if free from impurities:

	Pounds of calcium in one ton
Quicklime	1,429
Hydrated lime	1,082
Carbonate of lime	801

Expressed in percentages, the amount of calcium in hydrated lime is 75.7 percent, and that in carbonate of lime is 56 percent, of that in quicklime.

Considering the difficulty of grinding limestone to the fineness of division accomplished by burning it may be said that two tons of finely ground limestone should be computed at the same value, when spread on the field, as a ton and a third of hydrated lime or one ton of quicklime.

It must be remembered, however, that when quicklime or hydrated lime is exposed to the air it begins to revert to the carbonate form, so that it is difficult to obtain a quicklime that does not contain some hydrated lime, or a hydrated lime that does not contain some carbonate. This is especially true of the so-called "agricultural" lime, which is likely to be a refuse product, containing unburnt cores, ashes and other impurities, which make it unfit for building purposes; hence, the safest material to buy is finely ground raw limestone, and this, of course, should only be bought on a guaranteed analysis, both as to content of the carbonates of calcium and magnesium and as to fineness of grinding.

Fineness of grinding limestone—When either quicklime or hydrated lime is mixed with moist soil it combines with the carbon dioxide which soil always contains, and reverts to the carbonate, but its particles are so small as to render them much more quickly soluble in the soil water, or in the dilute nitric acid produced by the nitrifying bacteria, than the coarser particles of the ground stone, which accounts, in part at least, for the greater effectiveness of the stone that has been burnt over that used in the raw condition.

The hundred tons of chalk that it is supposed were spread over Broadbalk Field more than a century ago, under the crude methods of pulverizing that were then available, probably contained no more immediately effective lime than would have been found in a single ton of quicklime; but this great dressing has furnished a supply that has slowly become available, year by year for a century, and it may sometimes be advisable to use a coarsely ground limestone rather than the finer material, if the fact be kept in mind that it is only the fine material that will give immediate results.

A study of this question was begun in 1915, at Wooster, in a four-year rotation of corn, oats, wheat and clover. The land given to this test is similar in character and had had a similar previous history to that of the test described on page 88. It receives a basic treatment of eight tons per acre of yard manure on corn and 320 pounds of superphosphate on wheat.

The "fine" limestone used in this test has analyzed about 85 percent calcium carbonate and 5 percent magnesium carbonate, 35 to 45 percent of it passing through a sieve having 100 meshes to the linear inch and all through one having 10 meshes to the inch.

The coarse limestone is the grade known as screenings, all passing through a quarter-inch sieve. The results of the comparison are shown in Table XVI, which gives the value of the increase from liming for the average four-year period during the twelve years, 1915-1926.

TABLE XVI.—FINENESS OF GRINDING LIMESTONE

Limestone per acre on every corn crop	*Value of increase per acre per rotation*
Fine, 2 tons	$22.57
Coarse, 2 tons	20.56
Fine, 4 tons	28.86
Coarse, 4 tons	26.17

Whether to use the fine or coarse limestone will depend upon the difference in cost, spread on the field.

This question has been very thoroughly investigated by Nicholas Kopeloff, whose conclusions, based upon personal experiment and a comprehensive review of the literature of the subject, and published in *Soil Science* for July, 1917, are that increase in fineness of division of pulverized limestone is responsible for a proportional increase in crop yields, and that limestone that will pass a 200 mesh sieve may be regarded as equally effective with burnt lime, pound for pound of calcium and magnesium contained.

How often should liming be repeated?—The familiar fact that drainage water is usually "hard" from lime held in solution suggests the possibility that excessive applications of lime in an immediately available form may result in considerable waste, and because of this possibility and of the greater cost of very fine grinding many investigators recommend the use of a stone ground to a medium degree of fineness, in cases where it may be more economical to make larger applications at less frequent intervals than smaller ones more frequently. Another factor, however, must be considered here, and that is that on previously unlimed land it seems to be necessary to make a sufficiently large initial application of lime to completely neutralize the acid condition. Thus in a field experiment on the Strongsville farm of the Ohio Station the twenty-year average increase from one ton of limestone of medium fineness has been as shown in Table XVII, the crops being grown in a three-year rotation on three tracts of land, each crop thus being grown every year.

The outcome of this test indicates that when the rate of application has not exceeded the equivalent of one third of a ton per annum it has been immaterial whether the lime-

TABLE XVII.—FREQUENCY OF APPLICATIONS OF LIMESTONE

BLOCK No.	*Basic treatment*[9]	*Annual value of unlimed crop*	*Plot No.*	*Distribution of limestone*	*Value of increase per ton limestone*
I	Superphosphate, 320 lb.	$18.00	2	1 ton every 3 yrs.	$19.86
			3	2 tons every 6 yrs.	21.58
			4	3 tons every 9 yrs.	20.63
II	Superphosphate, 320 lb. Nitrate of soda, 160 lb.	22.88	7	1 ton every 3 yrs.	10.39
			8	2 tons every 6 yrs.	12.97
			9	3 tons every 9 yrs.	13.55
III	Superphosphate, 320 lb. Nitrate of soda, 160 lb. Muriate potash, 160 lb.	21.83	12	1 ton every 3 yrs.	13.95
			13	2 tons every 6 yrs.	15.37
			14	3 tons every 9 yrs.	15.20
IV	Superphosphate, 320 lb. Nitrate of soda, 160 lb. Muriate potash, 160 lb.	22.92	17	2 tons every 3 yrs.	10.41
			18	4 tons every 6 yrs.	10.11
			19	6 tons every 9 yrs.	7.53
V	Superphosphate, 320 lb. Yard manure, 8 tons	26.43	22	1 ton every 3 yrs.	11.00
			23	3 tons every 6 yrs.	9.27
			24	6 tons every 9 yrs.	6.18
VI	Yard manure, 8 tons	20.91	27	1 ton every 3 yrs.	10.90
			28	3 tons every 6 yrs.	14.00
			29	6 tons every 9 yrs.	10.44

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[9] Each block receives the same basic treatment throughout, the first and fifth plots of the block being left unlimed as checks.

stone was applied at the rate of one ton every third year, two tons every sixth year or three tons every ninth year, the average being slightly in favor of the larger dressings at longer intervals. When the dressing has reached six tons there has been a reduction in the effect per ton of limestone except on the land receiving manure alone, where the difference is small.

In this test, as in those at Wooster, the combination of superphosphate and nitrate of soda has reduced the effect of the lime, while the addition of muriate of potash to this combination has increased it. The combination of superphosphate and manure has also apparently reduced the demand for lime by increasing the effectiveness of the manure.

CONCLUSIONS

Apparently, quicklime or hydrated lime is changed to the carbonate form very soon after incorporation with the soil; the chief advantage, therefore, in these carriers of lime is the greater fineness to which a limestone may be reduced by burning than by grinding, thus facilitating its solution in the soil, and the smaller weight of material required to carry a given quantity of calcium and magnesium.

The relative proportion of these two elements in a limestone does not appear to be a matter of practical importance.

Liming increases the activity of the nitrifying organisms of the soil, and hence the use of lime as a substitute for manure or fertilizer will eventually injure the land by wasting its store of organic nitrogen.

Liming and manuring or fertilizing, each increases the effectiveness of the other.

XI

Phosphorus, the Yoke-mate of Lime

PHOSPHORUS is a chief constituent of the animal skeleton and nerve tissues, in which it is found in the compound known as phosphate of lime, or, more strictly, calcium phosphate, since the term lime includes magnesium as well as calcium. Phosphorus is relatively prominent in the seed of the plant, whereas calcium and potassium are found more largely in the stem and foliage, as shown by Tables I and II.

Analyses of 126 Ohio soils, reported by Ames and Gaither,[1] show a total phosphorus content in the surface 6 inches ranging from 500 to 6,000 pounds per acre, the larger figure being reached only in a very limited area in Hamilton county, which possibly owes its greater supply of this element to an outcropping of a stratum of phosphatic limestone, similar to that which has made the "Blue Grass" region of Kentucky famous for its fertility. Such a stratum has been found in Franklin county, but there it is buried under other deposits.[2]

Black soils generally contain more phosphorus than the lighter colored soils, and calcareous soils more than non-calcareous, the average for Ohio soils containing calcium carbonate being 1,310 pounds per acre in the surface 6 inches, compared with 986 pounds for soils lying over sandstones.

Even this small quantity of phosphorus would seem to be sufficient to provide for nearly two centuries of cropping, were it not for the fact that it is never possible completely to exhaust the soil of any of the necessary elements of fertility, and long before the point of exhaustion is reached the diminishing yields give warning.

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[1] Ohio Exp. Sta. Bul. 261.

[2] Geological Survey of Ohio: Geology, Vol. III. p. 610.

Amount of phosphorus removed from the land—Whatever the system of farming practised, excepting only the conversion of all the farm produce into butter or sugar, with the most rigid saving and returning to the land of the manure, crop residues and buttermilk, there is a constant drain from the land of its fertilizing minerals. Seven 1,000-bushel carloads of corn or oats, or five such carloads of wheat, carry away as much phosphorus as is found in the plowed surface of an average acre of land, even though the stover and straw are conscientiously returned to the land; and ten 13-ton carloads of mixed hay, or half that quantity of alfalfa hay, carry as much phosphorus as seven carloads of corn.

Some farmers assume that, if the hay and most of the grain are fed on the farm, there will be no loss of fertility; but the animal must find in its food the elements required to build its skeleton and other tissues. Six carloads of fat cattle, or 14 carloads of fat hogs, may contain phosphorus equivalent to that contained in the surface 6 inches of an acre, and the milk from a dairy of 130 average cows will carry off this quantity of phosphorus every year.

When we add to these facts the further fact that very few farms have been so managed as to prevent the waste of a very large part of the manure it is not surprising that the northeastern counties of Ohio, the region in which dairying has been most extensively practised, should have been the first section of the State to manifest a deficiency of phosphorus in the soil.

Sources of phosphorus—From an early date English and European farmers had observed that animal bone possessed a peculiar fertilizing property. When modern chemistry began its revelations, in the laboratories of De Saussure, Liebig and Boussingault, during the first half of the Nineteenth Century, it was discovered that this property of bone was due to the element phosphorus, which, in combination with calcium as "phosphate of lime," constituted the major part of its substance. Chemistry also showed that the same combination was found in certain rocks, although in a form less available to crops than that in bone.

In 1834 a 20-year-old English boy, John Bennett Lawes, entered upon the management of his patrimonial estate of

Rothamsted, a farm of about 250 acres, adjoining the village of Harpenden, 25 miles northwest of London. His father had died when he was but eight years old. He had been sent to Eton and Oxford, but had developed little interest in classical studies, and left college without graduating. He had, however, become interested in the new science of chemistry, and at home he fitted up a chemical laboratory in which, in 1837, he began the study of the relation of that science to agriculture, by the application of certain chemicals to plants grown in pots.

First production of superphosphate from rock—At that time bone charcoal or *"boneblack"* was extensively used as a purifier for oils and other substances, and the attention of young Lawes was drawn to the possible value of the waste charcoal as a fertilizer. It had been found that the boneblack was made much more effective by treatment with sulphuric acid, a discovery that suggested the treatment of apatite and other mineral phosphates in the same manner, and in 1842 Mr. Lawes obtained a patent for and began the manufacture of "superphosphate" from such materials, thus laying the foundation for the modern fertilizer industry.

The original name, *"superphosphate,"* was changed to "acid phosphate" by American manufacturers, but since the discovery that acid soils are unfavorable to the growth of many of our principal crops this name has led many farmers to fear that this fertilizer might increase soil acidity, and the National Fertilizer Association has decided to return to the original name, superphosphate, the name by which it is internationally known.

The long-continued experiments which are being conducted in this country are showing that the fear of increasing soil acidity by the use of this fertilizer is groundless, as will be shown farther on.

Apatite, while still a considerable source of phosphorus, has fallen into comparative insignificance since the discoveries of enormous deposits of another phosphatic rock in several of the Southern and Northwestern states of America and in other parts of the world. It is to be expected that additional deposits of this character will be discovered in South

America, Asia and Africa, when the geological resources of these continents have been more fully ascertained.

Guano, which is the accumulation under the roosts of sea-fowl on tropical islands and of bats in caves, has been a considerable source of phosphorus. Guano had become an article of commerce long before the treatment of rock phosphate with sulphuric acid. It varied in composition, much of the nitrogen having been lost from the older deposits, and this natural variation was exaggerated by intentional adulteration, as it became a common practice for ships engaged in the guano trade to go out ballasted with gypsum and to return with a considerable part of this ballast mixed with the guano.

Basic slag, a by-product of the manufacture of steel from ores containing phosphorus, is another source of phosphorus. This product differs from the rock phosphate in being sufficiently soluble without treatment with acid and in containing a large proportion of lime, which makes it a very suitable fertilizer for acid soils, but when the soil has become very acid it is usually much more economical to correct its condition with lime than with basic slag.[3]

Comparison of phosphates—Superphosphate, made both from rock phosphate and boneblack ("dissolved boneblack"), steamed bonemeal and basic slag have been used in comparison in the 5-year rotation at Wooster and Strongsville, the phosphates being applied in quantities computed to carry the equivalent of four pounds of phosphorus per acre per annum and in connection with nitrate of soda containing 15 pounds of nitrogen and muriate of potash carrying 22 pounds of potassium, the object being to furnish more available nitrogen and potassium than would be necessary to completely balance the phosphorus given, to the end that the effect of the phosphate may not be limited by any deficiency of other elements.

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[3] This material has been called "Thomas Phosphate" in Europe, for the reason that it was originally produced under what was known as the "Thomas-Gilchrist" process. It was also sold at one time in America under the name of "Odorless Phosphate."

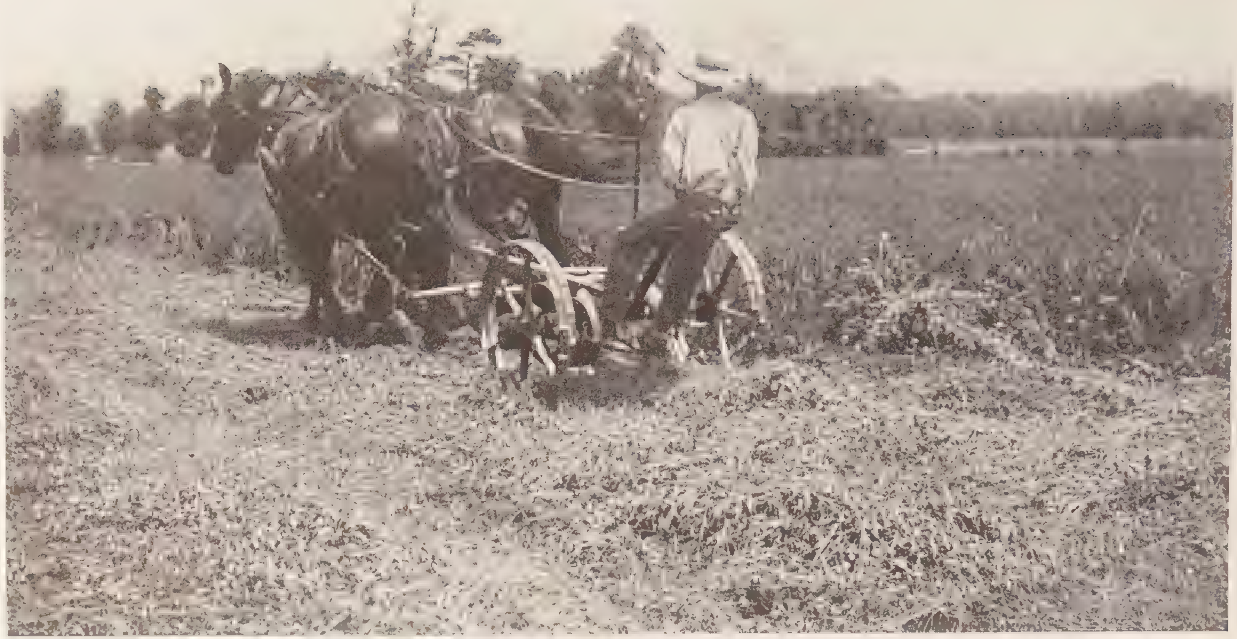

FIGURE VIII.—ALFALFA ON LIMED LAND

With lime, phosphorus, potassium and good husbandry alfalfa may be successfully grown over an even wider range of soil and climate than corn. Alfalfa refused to grow on this land until lime was added. Photo by E. J. Houser.

At Wooster half the land has been dressed with ground limestone, two tons per acre for every corn crop, the other half being left untreated. At Strongsville half the land has been similarly limed, while the other half was dressed with raw-phosphate rock, 1 ton per acre, for 13 successive corn crops, the raw phosphate being then discontinued but the liming maintained. The outcome of these tests is averaged in Table XVIII for the 20 years ending 1923 at Wooster and 1924 at Strongsville.

TABLE XVIII.—COMPARISON OF CARRIERS OF PHOSPHORUS

ANNUAL VALUE OF INCREASE PER ACRE DUE TO THE PHOSPHATE

	Wooster		*Strongsville*	
	Unlimed land	*Limed land*	*Limed land*	*Raw phosphate-treated land*
PHOSPHATE	*Dol.*	*Dol.*	*Dol.*	*Dol.*
Superphosphate	9.43	8.16	10.80	1.06
Dissolved boneblack...	7.07	6.61	9.27	...
Steamed bonemeal.....	7.20	5.78	7.97	1.34
Basic slag...........	8.94	5.72	9.67	2.07

The increases shown in Table XVIII are for the phosphates alone, after deducting the increase produced by nitrate of soda and muriate of potash, used without phosphate in parallel tests.

The two tests agree in giving the first place to superphosphate except on the raw-phosphate-treated land. Dissolved boneblack shows a lower effect than the rock superphosphate in every test. The boneblack for these experiments was treated with sulphuric acid in small quantities at the Experiment Station, as it had become difficult to procure it in the regular fertilizer trade, and it is possible that it was not so thoroughly acidulated as the commercial superphosphate. However, in the Pennsylvania experiment, in which boneblack superphosphate was used until 1915, the effect of the phosphate has been lower than in most of the Ohio tests. At any rate, there has been no loss in efficiency consequent upon the substitution of a superphosphate made from rock for one made from bone. Basic slag stands next to superphosphate at Wooster except on the limed land. Both basic slag and bonemeal seem to be slightly superior to the superphosphates for increasing the yield of the raw phosphate-treated land, apparently because the raw phosphate has not fully served the purpose of lime in neutralizing soil acidity.

FIELD EXPERIMENTS WITH SUPERPHOSPHATE

Table XIX (See Appendix) gives the annual basic yields and the increases due to liming and to superphosphate in field experiments with crops grown in rotation, conducted in several states and on soils of different geologic origin.

In many of these experiments part of the land has received a basic dressing of ground limestone or manure, one or both. In one of the Ohio tests the basic dressing has been raw phosphate rock. In most cases the limestone has been so used that its effect can be separated from that of the other treatments, but in a few cases all the land has been limed and only the effect of the superphosphate can be shown. In all cases the increase shown in the table for either limestone or superphosphate is for that treatment alone, in excess of the yield due to basic treatment. While the basic treatments have increased the total yield, they have sometimes reduced the apparent effect of the phosphate.

In order to make the results comparable they have been reduced, in the final columns of the table, to values per acre per annum, per ton of limestone and per 100 pounds of superphosphate of the 16 percent grade. Of course these valuations will not apply to every farm and every season, but they afford the most satisfactory basis of comparison.

In many of the tests the outcome is less dependable because of insufficiency of checkplots. The difficulty of securing sufficiently large areas of uniform soil to answer the multitude of questions perplexing the investigator; the lack of experimental knowledge, when the work was begun, of the variations that lie beneath the surface of the most uniform appearing soils; and paucity of funds, have led many workers in this new field of research to overlook the fact that, in so costly an enterprise as this, the neglect of any measure necessary to the greatest accuracy in results is a false economy. It would have been far better to postpone the attack on some of the problems and concentrate the work on the definite solution of a smaller number.

Because of these facts, and of the further fact that in very many cases the work has not yet covered a sufficient length of time to overcome the temporary irregularities usually found when a soil is first brought under experiment, and the variations due to seasonal change, the results of these tests can at present be accepted only as approximations to the truth. Their value lies in their general agreement on a few major points.

The limestone has usually been spread at the rate of two tons per acre, while the land was being prepared for corn, one application serving the entire rotation. In a few of the Ohio tests the rate has been one ton per acre, and in the Indiana and Kentucky tests the limestone has been applied but once or twice, at the beginning of the test, and then discontinued. The first method has given a somewhat larger increase per acre, and the second a little larger increase per ton of limestone.

The relation of the geologic origin of the soil to its hunger for lime is conspicuously evident. In the general average the soils of sandstone origin are paying nearly three times as much for a ton of limestone as those derived from limestone. The exceptional cases are Tests 12 and 46, classed with the sandstones, and 30, 37 and 48, classed with the limestones. Test 12 has a basic dressing of manure and superphosphate, both of which to some extent reduce the demand for lime. Test 30 is over the ancient Illinoian glaciation in Ohio and has been subjected to leaching for an immeasurably longer period than other Ohio tests on soils of limestone origin; Test 37 (in which the increase shown for liming is that over unlimed land, whereas that for superphosphate is over limed land) is in approximately the same latitude as No. 30 and presumably upon a similar soil in Indiana; Test 46 is within the western coal field of Kentucky, and limestone strata, which are frequently found in the coal measures, have probably contributed to the soil formation, and Test 48 is within the St. Louis or Mammoth Cave limestone area of southwestern Kentucky. The Kentucky soils included in this table are all residual soils, lying south of the glaciated area of the northern states, and have therefore been subjected to conditions which would remove their more soluble constituents for a much longer period than those protected by glacial covering. The loess, which has covered many of the southwestern soils, seems not to have been a carrier of lime.

Liming has usually increased the total effect of the phosphate, the exceptions being the Wooster and Scottsburg soils, on which liming has increased the total yields, but has somewhat reduced the relative effect of the phosphate, because of the increase in basic yield.

The increase credited to the phosphate has usually been smaller on manured than on unmanured land, presumably because manure carries some phosphorus. This does not mean, however, that it has not been profitable to add phosphate to manure, as will be more fully shown in Chapter XXI.

Full effect of superphosphate not realized if used alone—The results given in the table under consideration are for superphosphate used alone. That the full effect of the phosphate is not always realized when so used is illustrated by tests in which the same quantity of phosphate is used alone and in combination with nitrate of soda or muriate of potash, one or both, under such conditions that it is possible to determine with reasonable accuracy the relative effect of each component of the fertilizer in the combination. The outcome is that the phosphate shows a considerably greater efficiency when used in such combinations than when used alone.

Many of the experiments listed in this table have not yet had time to show the full effect of the treatment. For example, the annual increases in the Ohio tests at Wooster and Strongsville have been considerably smaller for the first ten years (Nos. 1 and 8) than for the succeeding periods (Nos. 2, 3 and 9), these divisions being parts of the same consecutive experiments, which have been running 35 years at Wooster and 33 years at Strongsville. In the 40-year Pennsylvania test, also, the effect during the first 25 years was much smaller than during the succeeding 15 years (Nos. 31 and 32).

Seasonal variations affect both yield and increase, but the results of the Ohio experiments, including those on the outlying farms, indicate that, as a rule, eight to ten years of systematic treatment will be required to develop the full effect of either fertilizer or manure.

The outcome in the Wooster tests also strongly suggests that increasing lime deficiency in the soil may become a potent factor in increasing the effect of superphosphate, which seems to serve as a partial source of lime supply as well as of phosphorus.

There has been a wide range in the rate of application of the phosphate. In the 5-year rotations at Wooster and Strongsville it has been used at rates equivalent to 70 pounds per acre of the 16 percent grade on corn and oats and 140 pounds on wheat, equivalent to an annual dressing for the 5-year period of 56 pounds. In the Pennsylvania and Indiana tests it has been divided between the corn and wheat, the annual rate being equivalent to 150 pounds in Pennsylvania and 83 to 113 pounds in Indiana. In the Kentucky tests it has all been applied to the corn, at rates equivalent to 115 to 150 pounds per acre per annum.

Taken as a whole, the results indicate that the quantity used in the older Ohio tests might have been increased with additional profit, but that the larger dressings have sometimes been more than the crops could utilize in the absence of larger supplies of available potassium than the untreated soils have furnished.

The superphosphate has been distributed as shown in the table. The one experiment (Tests 40 and 41) in which it has all been given to the wheat shows a relatively low increase per hundred pounds of phosphate, and a similar outcome has followed in several of the tests in which it has all been given to corn. The better practice would seem to be to divide it between the corn and wheat.

Superphosphate hastens maturity—This practice is supported by the fact that superphosphate has a marked effect in hastening maturity, an effect that is usually—though not always—desirable for both corn and wheat, especially if the planting of the corn or the maturing of the wheat has been delayed by unfavorable spring weather.

This effect has been more definitely shown by superphosphate than by bonemeal or basic phosphate in the Ohio tests, and it is probably to be expected in the crop receiving the direct application, rather than in those that receive only the residual effect of the fertilizer.

In the Ohio tests, and presumably in all the others, the superphosphate has been applied to all the land, for corn as well as for the other crops, in order to secure its full effect on the entire rotation, as experience has shown that the full effect of the fertilizer is never realized in the crop to which it is applied, and only by this method can the small grains and clover, which follow corn in such rotations, receive the full residual effect of the fertilizer. This point is well illustrated by the fourteen experiments, listed in the table under consideration, in which the corn receives all the fertilizer; the average value of the increase of corn being less than half that of the succeeding crops, at the prices employed in these computations.[4]

Grades of superphosphate—As stated above, when these experiments were begun the common grade of superphosphate, as made from Florida, South Carolina and Tennessee rock, was sold to contain 14 percent available phosphoric acid, this grade being produced by the mixing of sulphuric acid and the powdered rock in approximately equal weights. The better grades of this rock, in its natural state, analyze around 28 percent phosphoric acid, and when a ton of 28 percent rock was mixed with a ton of sulphuric acid the product was two tons of 14 percent superphosphate—or acid phosphate, as it was then called in America.

With improvements in the purity of the rock selected and in process of manufacture the available phosphoric acid was increased to 16 percent, which became the standard grade for a number of years, and during recent years further improvements have made it possible to purchase superphosphates containing 18 to 20 percent or more of phosphoric acid, at costs per pound of phosphoric acid even lower than the cost in the lower grades, because of the saving in freight costs on useless material.

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[4] Recent experiments have indicated that in an unfavorable season the maturity of corn may be hastened by applying part of the fertilizer in the hill, but these tests have not yet been carried long enough to determine whether this advantage is sufficient to overcome the disadvantage of uneven growth in the small grains and hay crops that follow the corn in rotation. In parallel tests the increases following long continued systematic treatment have been greater from broadcast, than those thus far realized from hill fertilizing.

So long as these high grade superphosphates are honestly made their use is to be recommended, but the purchaser should insist upon the guaranty of availability, for the incomplete acidulation of the rock would result in a product showing a high percentage of phosphoric acid, but one likely to be inferior in effect. The effect of the substitution of raw phosphate for superphosphate will be considered in the next chapter.

CONCLUSIONS

The results of these experiments seem to justify the following conclusions:

1. That there are comparatively few fields in the northern Mississippi Valley, which have been in cultivation or pasturage for half a century or longer, on which the cereal crops and clover will not respond profitably to superphosphate.
2. That superphosphate, properly made from phosphatic rock, is fully equal in effect, pound for pound of phosphorus contained, to that made from animal bone, and that it is superior to untreated bone.
3. That, instead of increasing soil acidity, superphosphate has a slight neutralizing effect, but that this effect is not sufficient to render the liming of acid soils unnecessary.
4. That the full effect of superphosphate is only attained when it is supported by ample supplies of available nitrogen and potassium.
5. That basic phosphate may be practically equal to superphosphate on acid soils, pound for pound of phosphorus contained, but that on neutral soils the superphosphate is superior.

XII

Raw Phosphate

SUPERPHOSPHATE is made by treating ground raw phosphate rock with sulphuric acid, the object being to render the phosphate more soluble. The question has naturally arisen whether this treatment is really necessary, especially if the rock be ground to a very fine powder and if this powder be mixed with some fermenting material, such as farm manure or other organic matter, and a number of experiment stations have been at work on this problem for many years. The following examples of this work are selected as applying most directly to the agriculture of the corn and wheat belt of the United States.

REINFORCING MANURE WITH PHOSPHATES

Ohio—Since 1897 the Ohio Experiment Station has grown corn. wheat and clover, each crop being grown every year in a 3-year rotation in which a dressing of eight tons of farm manure per acre is plowed under for every corn crop, the manure being applied on part of the land without any treatment and on other parts after reinforcement with raw phosphate or superphosphate, the reinforcing materials being mixed with the manure at the rate of 40 pounds of each to the ton of manure. Half the manure in each treatment is applied fresh from the stable in January, and half has been exposed in flat piles in the open barnyard until April, when all is plowed under. In the present discussion the results are averaged for the fresh and exposed manures, as probably most nearly approximating the condition in which manure is used on the average farm.

Since 1905 the land has received for each corn crop a dressing of ground limestone, applied to the surface at the rate of about two tons per acre while the land is being prepared for corn.

This treatment has incorporated the reinforcing materials with manure used on a clover sod, thus securing the effect of decaying organic matter in both manure and clover roots.

Before the inauguration of this test the land had been used in general cropping, with little or no manuring or fertilizing of any kind. The test is located on the Wooster farm of the Station.

The outcome of this test is shown in Table XX which gives the average yields from the differently treated manures for the nine years before liming was begun, and for two periods, one of nine years and one of twelve years since, together with the value of the increases due to the treatment, computed per acre and per 100 pounds of phosphate.

Table XX.—Comparison of Raw Phosphate and Superphosphate as Reinforcements of Manure

	Average annual yield per acre			*Value of increase*	
Treatment of Manure	*Corn* *Bu.*	*Wheat* *Bu.*	*Hay* *Cwt.*	*Per acre per annum* *Dol.*	*Per 100 lb. phosphate* *Dol.*
First period, 9 years, unlimed					
None..........	54.28	18.03	27.90	...	...
Superphosphate	60.67	24.82	39.76	6.90	6.46
Raw phosphate	60.08	24.96	41.71	7.20	6.75
Second period, 9 years, limed					
None..........	61.47	22.72	42.53	...	...
Superphosphate	71.19	28.81	49.42	6.51	6.09
Raw phosphate	71.37	26.44	48.16	5.32	4.98
Third period, 12 years, limed					
None..........	64.42	29.39	42.42	...	...
Superphosphate	72.11	34.43	48.79	5.42	5.07
Raw phosphate	70.46	30.73	44.36	2.56	2.40

During the first period the total value of all the crops was slightly greater under the raw phosphate than under the superphosphate treatment. When liming was begun there was a considerable increase in yield of all the crops, which was relatively greater from the untreated than from the phosphated manures, but the raw phosphate fell behind the superphosphate. During the third period there was a further increase in the yields of corn and wheat from the untreated and superphosphate-treated manure, but the raw phosphate fell still farther behind. It is true that the increase from raw phosphate during this period would still be considered very profitable, had not that from the acid phosphate been so much greater.

Comparison of phosphates on limed and unlimed land—In 1905 a second test was begun at Wooster in a 3-year rotation of corn, oats and clover, on land that had been kept in good condition by systematic manuring and crop rotation. In this test part of the land has been left continuously unlimed, while lime and limestone have been used on other parts, both alone and in conjunction with manure and phosphates. Some of the results of this test are shown in Table XXI.

TABLE XXI.—COMPARISONS OF RAW PHOSPHATE AND SUPERPHOSPHATE. AVERAGE ANNUAL VALUES OF INCREASE PER ACRE BY PERIODS

TREATMENT PER ACRE FOR THREE-YEAR ROTATION ALL ON CORN	*Annual value of increase*	
	First 12 years	*Last 12 years*
Raw phosphate, 320 lb.	2.10	3.20
Superphosphate, 320 lb.	3.46	3.70
Raw phos., 320 lb.; Mur. pot., 40 lb.	3.19	5.50
Superphosphate, 320 lb.; Mur. pot., 40 lb.	5.63	5.42
Raw phos., 320 lb.; Mur. pot., 40 lb.; Quicklime, 1,000 lb.	7.19	15.21
Superphos., 320 lb.; Mur. pot., 40 lb.; Quicklime, 1,000 lb.	9.46	17.39
Quicklime, 1,000 lb.	4.66	10.12
Manure, 8 tons	7.30	11.55
Manure, 8 tons; Raw phosphate, 1,000 lb.	8.36	14.59
Manure, 8 tons; Quicklime, 1,000 lb.	8.65	17.31
No treatment: value of total produce	23.16	17.54

The effect of liming shows that this soil is becoming increasingly acid. One thousand pounds of quicklime has added $1.35 to the effect of eight tons of manure during the first period and $5.76 during the last, showing that while manure exerts a considerable neutralizing influence it alone is not sufficient for such a soil as this. This point is brought out more forcibly by Table XXII, which gives the yield and increase per acre for the hay crops from the different treatments for the two periods, per acre per annum.

TABLE XXII.—AVERAGE YIELD AND INCREASE OF HAY BY PERIODS

TREATMENT	*Yield* First 12 years Cwt.	*Yield* Last 12 years Cwt.	*Increase*[1] First 12 years Cwt.	*Increase*[1] Last 12 years Cwt.
Raw phosphate	35.2	15.7	1.4	3.4
Superphosphate	37.3	15.3	2.6	1.1
Raw phosphate, mur. pot.	34.3	15.0	1.6	3.4
Superphosphate, mur. pot.	39.0	15.2	4.3	1.6
Raw phosphate, mur. pot., lime	44.5	44.4	10.1	29.4
Superphosphate, mur. pot., lime	46.4	45.0	12.3	29.9
Quicklime	42.5	38.4	8.2	23.5
Manure	40.7	21.1	8.9	10.3
Manure, raw phosphate	45.0	29.0	9.8	13.7
Manure, lime	50.1	48.7	10.8	26.3

Table XXII shows that for the clover crop lime has been far more important than any other treatment, and that, whereas under every other treatment the yields of clover show a large decline during the second period as compared with the first, the yields have been nearly maintained when liming has been added to fertilizing or manuring.

Melilot (sweet clover) a plant still more sensitive to lime deficiency than red clover, has been substituted for red clover in this test since 1921, with the outcome that where lime has been omitted from the treatment the hay has consisted almost altogether of weeds and volunteer grasses, even on the manured land and that treated with manure and raw phosphate, hence the weight of hay, as given in Table XXII, tells only part of the story; and while the other crops have not yet suffered from lack of lime to the same extent as the clover, the present indications point to further decrease in the yields in all the crops on the unlimed land.

This decrease is progressing more slowly where raw phosphate than where superphosphate is used, but the difference is too small to be of material significance. It is true that, when used in the absence of lime, the two phosphates give practically equal total crop increases, but where lime is added, as it must be on this land before it can be worked with profit, the increased effect of the superphosphate on the other crops of the rotation has more than offset the lower cost of the raw phosphate, even though that cost were only half that of the superphosphate.

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[1] Computed by comparison with neighboring checkplots.

A third test was begun at Wooster in 1915, in which the two phosphates are used in a four-year rotation of corn, oats, wheat and clover at the rates of 480 pounds of superphosphate and 768 pounds of raw phosphate per acre per rotation, over a basic treatment of eight tons of manure and two tons of ground limestone, the entire treatment being applied to the corn crop. The outcome for the first 12 years has been an increase per rotation of $37 for the superphosphate and of $22 for the raw phosphate. At the time the test was begun the cost of the two treatments was practically the same.

In 1905 an experiment in the reinforcement of manure with raw phosphate was begun at the Germantown farm of the Ohio Station, the soil of which is a resultant of the decomposition of glacial drift composed largely of limestone gravel. The phosphate was mixed with manure at the rate of 40 pounds per ton of manure which was applied to corn at the rate of five tons per acre in a 3-year rotation of corn, wheat and clover.

At the end of 15 years the increase for the phosphated manure was but $2.50 per rotation—or 50 cents per ton of manure—greater than that from the same quantity of manure used without treatment. Superphosphate was then substituted for the raw phosphate and for the next nine years the increase from this treatment has been $11 per rotation in excess of that from manure alone, or $2.20 per ton of manure:

RAW PHOSPHATE A PARTIAL SUBSTITUTE FOR LIME

The Strongsville test—The soil of the Strongsville farm (Northeastern Test Farm) of the Ohio Experiment Station contains more clay than that at Wooster, and for about 25 years before it came under the control of the Experiment Station it had been used for pasturage. Under this treatment its supply of available phosphorus had become so reduced that the crops have responded to this element in the fertilizer to an even greater extent than at Wooster.

In 1895 a 5-year rotation was begun on this farm, duplicating the one begun the previous year at Wooster, and in 1905 the range of 40 plots about to be planted to corn was cross-dressed on the south half with quicklime and on the north half with ground raw phosphate, each applied at the rate of one ton per acre and over all the land, fertilized and unfertilized alike. After the first liming ground limestone was used at the rate of two tons per acre instead of quicklime. This treatment was continued until the five ranges had been gone over once and three of them the second time. After 1912 the phosphate treatment was discontinued, but the liming has been repeated on every corn crop.

Owing to a mistake in application it has been necessary to discard one of the ranges (E) from the present computation, and the timothy crop also is omitted because of several failures. The experiment therefore is treated as a 4-year rotation of corn, oats, wheat and clover. Because of these omissions the number of crops harvested in this test since 1905 has been 15 each of corn and oats, 13 of wheat and 14 of hay, the wheat failing one season and being replaced by oats. The total value of these crops has amounted to $1,087 on the land receiving limestone only, and to $1,528 on that receiving raw phosphate only.

No land was left without either limestone or raw phosphate in this test, but in another experiment on the same farm and on a similar soil, in which corn, oats and clover are grown in rotation, the 20-year average value of the increase from a ton of limestone has amounted to almost $12. If, therefore, we deduct $360 for the 30 tons of limestone used we have left $727 as the probable basic yield of the land. Subtracting this amount from the gross yield of the raw-phosphate treated land we have $801 as the probable productive effect for six tons of raw phosphate, or $133 per ton of phosphate, a result that would seem most abundantly to justify its use.

On the limed land the results show a total gain for fertilizing of $598. An analysis of the effects of the separate treatments shows that more than 80 percent of this gain has been due to superphosphate, of which the equivalent of 4,200 pounds, or 2.1 tons, of the 16-percent grade, have been used during the test; the increase due to the superphosphate, therefore, has had a total value of $478, or of more than $220 per ton of phosphate. In other words, the return from a dollar invested has been $9.50 for raw phosphate and more than $22 for superphosphate, at the prices here employed.

It is true that no treatment of the limed land has produced as large a total yield as has been obtained from the phosphate-treated land, but this seems simply to mean that the demand for phosphorus has not been satisfied on the limed land. The superphosphate applied during the test has contained a total of 250 pounds of phosphorus, against 1,300 pounds given in the raw phosphate, but even after this large dose the raw phosphate-treated land has given a further increase in yield when superphosphate has been added to the raw phosphate, as shown in Table XXIII, which gives the total values for the entire period from the basic treatments, and the excess over this total due to the addition of superphosphate to the basic treatments.

Table XXIII.—Excess Increase for Superphosphate When Added to Raw Phosphate

		Basic treatment and values			
		Limestone		*Raw phosphate*	
Plot No.	*Treatment*	*Total value Dol.*	*Excess for superphosphate Dol.*	*Total value Dol.*	*Excess for superphosphate Dol.*
0	Basic treatment alone..	1,087	...	1,528	...
2	Superphosphate	1,642	558	1,628	100
3	Muriate potash	1,169	...	1,463	...
8	Muriate pot., superphos.	1,631	462	1,766	303
5	Nitrate soda	1,106	...	1,667	...
6	Nitrate soda, superphos.	1,666	560	1,869	202
9	Muriate pot., nit. soda.	1,188	...	1,864	...
11	Muriate pot., nit. soda, superphos.	1,753	565	1,920	56
17	Muriate pot., nit. soda, superphos.	1,809	621	1,988	124

Even on Plot 2, which receives no other fertilizer, the addition of superphosphate increases the effect; and also on Plot 17, which receives only half as much nitrogen as Plot 11, but 50 percent more superphosphate, the yield is greater than that of Plot 9, which receives no other phosphate than raw phosphate, the dressing of nitrate of soda on Plot 9 being twice that on Plot 17, and that of muriate of potash being the same for both plots.

Plot 18 in this test receives yard manure, eight tons per acre each on corn and wheat, and on the raw phosphate treated land yields a total value of $1,717, as against $1,864 on Plot 9, which receives for each rotation 480 pounds of nitrate of soda and 260 pounds of muriate of potash, but no other phosphate than the raw phosphate. It appears, therefore, that manure has not been as effective a coadjutor of raw phosphate as has the combination of nitrate of soda and muriate of potash.

The total cost of the superphosphate, as used in this test, has been only about half as much as that of the raw phosphate, but the combined cost of superphosphate and limestone has been considerably greater than that of the raw phosphate. Taking the results as a whole, in connection with the other experiments in liming on the same farm, there seems to be no reason to doubt that more limestone has been used than was necessary, and that if part of the money expended for limestone had been used to increase the dressing of superphosphate the net outcome would have been in favor of superphosphate.

During the earlier part of the seasons these Strongsville fields have indicated a larger growth on the limed than on the raw phosphate-treated land, but in the final harvest the greater development of the grains and seeds, due to the abundant supply of phosphorus, has thrown the balance on the other side.

Indiana—Comparative experiments with superphosphate and raw phosphate were begun on the Scottsburg farm of the Indiana Experiment Station in 1906, on the Worthington farm in 1911 and on the Moses Fell Annex farm in 1917. These farms are all located in the southern half of the state and on acid soils. As summarized by that Station in 1926 the outcome has been that superphosphate has been more profitable on limed or manured land, while raw phosphate has given the larger net return on untreated land. The cropping has been a 3-year rotation of corn, wheat and clover in each experiment.

Kentucky— In the experiments described on page 95 part of the land has received superphosphate and part raw phosphate, the phosphates being applied at the rate of 800 pounds per acre of superphosphate and 1,600 pounds of raw phosphate for the first two rounds of the rotation, after which the dressings were reduced to half these quantities except at Fariston, where the full dressings have been maintained. At Fariston, therefore, the treatment has been equivalent to an annual dressing of 200 pounds per acre of superphosphate and of 400 pounds raw phosphate, and on the other fields of 115 to 120 pounds of superphosphate and twice as much raw phosphate for the periods under consideration, the whole being given to the corn crop for each rotation.

The outcome of these treatments is shown in Table XXIV, compiled from Bulletin 272 of the Kentucky Experiment Station, which shows that on the unlimed land the raw phosphate has usually given the larger increase, while the superphosphate in most cases has been the more effective on limed land. The large increase for lime (see Table XIX), shows that these soils are all very acid. Considering the two phosphates separately, it appears that superphosphate has always been more effective on limed than on unlimed land in these tests, while with raw phosphate the results are contradictory, the increase being greater on limed land in three of the tests and on unlimed land in the other three.

The effect of both phosphates has been greater on the unmanured land of the Fariston test than on the manured land of the other fields.

Experiments conducted at Lexington indicate that the soils of the Blue grass region are indifferent both to phosphate fertilizing and to liming. Apparently the phosphatic limestone of this region lies so near the surface that it is still furnishing both lime and phosphorus in sufficient quantity.

Illinois—In the experiments listed in Table IX raw phosphate has been applied to the clover sod at the rate of a ton

TABLE XXIV.—COMPARATIVE EFFECT OF PHOSPHATES ON KENTUCKY SOILS
ANNUAL VALUE OF BASIC YIELD AND INCREASE PER ACRE

STATION	*Location and geology*	*Annual value of basic yield*	*Annual value of increase*			
			Unlimed land		*Limed land*	
			Super-phosphate	*Raw phosphate*	*Super-phosphate*	*Raw phosphate*
		Dol.	*Dol.*	*Dol.*	*Dol.*	*Dol.*
Berea	Eastern: Devonian shales and sandstone	16.98	4.62	3.71	6.51	5.46
Fariston	Eastern coal field...............	6.59[2]	8.74	11.42	14.12	9.02
Greenville	Western coal field................	13.46	6.85	8.95	10.32	6.81
Russellville	Southwestern limestone...........	16.67	4.51	5.58	5.01	3.69
Lone Oak	Western alluvium and loess.......	18.81	1.10	1.69	4.25	4.10
Mayfield	Western alluvium and loess.......	15.94	1.76	3.75	4.10	4.09

[2] Except at Fariston the land has all had a basic dressing of manure. The increases given are in excess of those due to manure.

per acre, once in each rotation, in preparing the land for wheat, on land that also receives a basic dressing of limestone and either manure or crop residues, the usual practice having been to plow under the phosphate with the clover or clover stubble for wheat; to apply the limestone to the surface in preparing the seedbed for wheat, and to apply manure to corn on the "live-stock farming" side or to plow under the corn stover and other residues on the "grain-farming" side. The phosphate has thus been used only as an adjunct to a basic treatment with manure and limestone, or crop residues and limestone, and its function is therefore limited to the purveying of phosphorus.

The table shows the average value of the increase for each 4-year period; that is, the increase due to one ton of raw phosphate. If the cost of the phosphate, spread on the land, be computed at $10 a ton, there are but three of the 19 fields—Joliet, Kewaunee and Oblong—in which the increase due to the phosphate, as averaged for the two systems of farming, has been sufficient to pay its cost.

In only a few of these Illinois fields has there been a direct comparison between raw phosphate and superphosphate. In the 41st Annual Report of the Illinois Experiment Station is reported the outcome for the rotation period, 1924-1927, of five such comparisons, in the general average of which the value of the increase, as computed by the Illinois Station at a somewhat higher range of prices than those hereinbefore employed, has been 58 cents for 100 pounds of raw phosphate and $1.48 for 100 pounds of superphosphate.

It has been assumed, in planning these experiments, that raw phosphate may be spread on the field at half the cost of superphosphate, pound for pound. It is doubtful whether this assumption will hold good on the average farm, but even if it should, the raw phosphate has been much less economical than the superphosphate in these tests.

This low return for superphosphate raises the question whether the loessal soils of Illinois may not be less responsive to phosphates than those of the older states, and whether the rate of application has not been larger than the crops were able to utilize and therefore that a more profitable increase might have been secured from smaller applications.

For example, in the Ohio experiments, Test No. 7, of Table XIX, is a three-year rotation of corn, wheat and clover with a basic dressing of manure and limestone, in which the corn receives 320 pounds of superphosphate per acre, none being given to the wheat or clover, thus making the equivalent of 107 pounds annually, while Test No. 5 is a four-year rotation of corn, oats, wheat and clover with a basic treatment of limestone only, but with 250 pounds of superphosphate on each of the four crops of the rotation. Tests 26 and 28 are three-year rotations of corn, wheat and clover, on land receiving no basic treatment, the corn and wheat receiving 200 pounds each of superphosphate in No. 26 and 120 pounds in No. 28, equivalent to annual dressings of 133 pounds and 80 pounds, respectively. Eliminating the oats crop in No. 5, with its share of phosphate, the outcome in these tests is compared in Table XXV.

TABLE XXV.—COMPARISON OF LARGE AND SMALL DRESSINGS OF SUPERPHOSPHATE IN OHIO EXPERIMENTS

Test No.	*Annual value of basic yield*	*Superphosphates per acre per annum*	*Value of increase for phosphate*	
			Per acre per annum	*Per 100 lb. phosphate*
	Dol.	*Lb.*	*Dol.*	*Dol.*
5	33.86	250	7.85	3.14
7	30.74	107	7.08	6.61
26	18.91	133	6.57	4.94
28	18.37	80	5.89	7.36

The largest return for 100 pounds of fertilizer may not always be the most profitable return. If, in the comparisons given in Table XXV, the cost of the phosphate be reckoned at one dollar per 100 pounds, the net return per acre in Test 26 will remain a few cents greater than that in No. 28, while that in No. 7 will be greater than that in No. 5.

When the rate of application exceeds the demands of the crops the comparative effect of different fertilizing materials will be obscured, for so long as the inferior fertilizer supplies this demand no superiority in the better one can produce any further effect.

When the tests we are considering were planned there was no experimental knowledge sufficient to serve as a guide in determining the rate of treatment most likely to secure a reliable answer to the questions involved. Even chemical analysis of crops and fertilizers was not sufficient, because of insufficient knowledge of the feeding capacities of different crops and of the availability of fertilizing materials. The object of the experiments was to secure such knowledge.

A few years ago the Pennsylvania Railroad surveyed five different routes between two points in its line in the effort to find a better grade, but all were finally abandoned in favor of a sixth and longer route.

The experiments we are studying were simply the preliminary surveys of the soil engineer, who had not even the advantage of the visible inspection which the railway engineers made before undertaking their surveys, and the results obtained are no more to be criticised because of their negative outcome than are the railway engineers to be condemned for their studies of routes that proved to be impractical.

It is often quite as important—sometimes even more important—to determine the wrong method than the right one, and the field experiment which gives negative results may be quite as valuable as the one which points to a change in farm practice.

In discussing the results of the earlier experiments of the Illinois Station the authors of Bulletin 273 say:

> "Experience with this more or less uniform system of cropping and soil treatment has revealed that it cannot be universally used with satisfactory response. Its practice for several rotations on some fields appeared to develop conditions which had a depressing effect upon crop yields. In some instances the small grains lodged frequently. Because of the more or less complex interrelationship of the various factors concerned, the exact causes for their behavior were not clearly understood. In some cases the amount of nitrogenous organic matter incorporated into the soil may have become excessive and thus brought about the unfavorable conditions for the rotation practice. In some cases the difficulty may have been due to the continued use of straw residues. In

> other cases it may have been due to application of mineral fertilizers in improper proportions or amounts. Whatever the reason or reasons may have been, it became clear during the past few years that some deviations from the standard practices should be instituted." [3]

It is then stated that the return of crop residues and the applications of limestone and raw phosphate have been reduced or temporarily discontinued. It will require several rotations fully to determine the effect of these changes.

CONCLUSIONS

From the experiments described in the foregoing pages the following conclusions seem to be warranted:

1. As a carrier of phosphorus alone, raw phosphate is distinctly inferior to superphosphate, and this inferiority is not counterbalanced by the difference in cost usually prevailing, nor is it overcome by admixture with manure or other organic material.
2. Raw phosphate performs some of the functions of lime, and this fact may sometimes justify its use; as, for example, on acid soils so situated that the cost of liming is relatively high and that of the raw phosphate comparatively low.
3. Raw phosphate, used in larger quantity than would generally be found economical, has not made an acid soil hospitable to sweet clover, hence it would be necessary to select a more acid-resistant crop than this to maintain the nitrogen supply where the raw phosphate is substituted for lime.

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[3] Ill. Exp. Sta. Bul. 273, p. 44.

XIII

Potassium

The table on page 45 shows that, while the quantity of phosphorus in the stover and straw of the cereals is relatively small, as compared with that in the grains, the reverse is the case with respect to potassium. The leguminous plants, however, while carrying nearly as large a percentage of potassium in their straw as the cereals, carry a very much larger percentage in their seeds.

In the animal organism we find phosphorus constituting a large percentage of the skeleton and nerve tissues, whereas the chief function of potassium is apparently that of aiding in the assimilation of other elements, as it is not stored in any considerable quantity.

Sources of potassium—Potassium is found in ordinary soils in very much larger quantity than phosphorus. It is a constituent of many rocks, especially feldspar and mica, and as these disintegrate in weathering the potassium is left in the soil, either in small fragments of the original rocks or as a constituent of clay, which removes the salts of potassium from solution and holds them in insoluble form, while the salts of sodium, which is also a common rock constituent, are carried to the sea.

Many large deposits of common salt (sodium chloride) have been found, which are supposed to have been formed by the enclosure and gradual drying up of primeval seas, processes similar to those which are now in operation in the Dead Sea, the Great Salt Lake, and similar inland bodies of salt water, the basins of the primeval seas having been filled by shifting of the earth's crust or by glacial action. Such deposits have been found in eastern Ohio, in western New York, in Michigan, Texas, Kansas and other places, at depths ranging from a few hundred feet to half a mile.

Near Stassfurt, Germany, and in Alsace, France, deposits of potassium salts have been discovered, from which at present the world's supply of potassium for industrial purposes and soil fertilization is chiefly drawn. In western Nebraska the waters of a few small lakes yield potassium salts on evaporation; some potassium is being recovered from the saline deposits in southeastern California, and during the withdrawal of German potassium salts from commerce, caused by the World War, the United States government instituted experiments on the California coast in the production of such salts from seaweeds; but unless the rumored discovery in Texas of great underground deposits shall be confirmed, there is no other known source of potassium salts equal in magnitude and availability to the mines of Germany and France.

However, this need not be a cause for anxiety. Every acre of average soil, excepting the muck lands, contains in its upper 7 inches, 12 to 16 tons of potassium, and in the subsoil it is found in still larger quantity. At present this potassium is so securely locked in insoluble combinations that the farmer may not be able to unlock more than 50 to 100 pounds a year by the most expert lock-picking of which he is capable, but in view of the triumphs of modern science in unlocking the equally secure source of atmospheric nitrogen it cannot be doubted that, long before a potassium famine shall have overtaken him, man will have learned the combination to the soil storehouse of this element. Meanwhile, therefore, let us consider the methods by which we may most effectively use the available store of potassium now within our reach.

Making soil potassium available—The first of these methods is that of the use of the leguminous crops, especially clover, in systematic rotations. Table II shows that clover and alfalfa are much larger consumers of potassium than the cereals, and the inference would follow that these crops have access to stores of potassium not available to the cereals.

Through the mediation of the nodule organisms the legumes are able to secure more nitrogen than is available to the cereals, and this larger supply of nitrogen enables them to draw more freely upon the soil minerals, somewhat as the fertilizing of the cereals with nitrogen alone enables them to utilize more of the soil minerals than they would otherwise be able to appropriate. The legumes thus do more than merely add to the nitrogen supply, for they increase the supply of soil minerals, both by bringing them up from the subsoil through their deeper root growth, and by the action of their associated bacterial organisms, which require the minerals for their growth, and probably are able to obtain them directly from combinations that are unavailable to the crop plants, through reactions analogous to those by which atmospheric nitrogen is captured; but experience has shown that the time will come when the cereals will require more potassium than the legumes will be able to provide—when the legumes themselves will need more potassium than they are able to pry loose from the soil combinations, and thus, insofar as the mineral elements alone are concerned, the clovers are in the long run exhaustive, rather than recuperative crops.

Three commercial carriers of potassium are in common use as fertilizing materials: the muriate, the sulphate and kainit. Of these the muriate (potassium chloride) is most generally used and is considered the most effective, pound for pound of actual potassium, but it is thought to be somewhat injurious to the burning quality of tobacco. Kainit is a crude salt, containing 13 percent or less of actual potash (K_2O), and because of its large proportion of inert matter, on which freight must be paid, it is usually less economical than either of the other salts, even though the price per ton may be much lower. The muriate and sulphate may be bought to carry about 50 percent actual potash, or nearly 4 times as much as kainit.

At the Germantown (Montgomery county) farm of the Ohio Experiment Station a 3-year rotation of tobacco, wheat and clover was begun in 1903 and is still in progress, in which the muriate and sulphate are applied in equal quantities of potassium and in conjunction with superphosphate and nitrate of soda, with the outcome shown in Table XXVI.

TABLE XXVI.—COMPARISON OF MURIATE AND SULPHATE OF POTASH IN TOBACCO-WHEAT-CLOVER ROTATION, OHIO EXPERIMENT STATION, AVERAGE INCREASE AND VALUE PER ACRE PER ANNUM, 24 YEARS, 1903-1926.

	Increase			
POTASSIUM CARRIER	*Tobacco* *Lb.*	*Wheat* *Bu.*	*Hay* *Cwt.*	*Value*[4] *Dol.*
Muriate, unlimed land....	636	16.05	14.21	20.13
Sulphate, unlimed land....	603	16.13	15.15	19.80
Muriate, limed land.......	603	18.95	17.71	21.49
Sulphate, limed land......	574	16.98	16.67	19.30

Liming has diminished the yield of tobacco and increased that of wheat and clover. On both unlimed and limed land the increase of tobacco is greater for the muriate than for the sulphate, and the same is true for wheat and clover on the limed land, while the reverse is the case on the unlimed land. The differences, however, are too small to be of much consequence.

In many field experiments with fertilizers a part of the land receives superphosphate only; a part the same dressing of superphosphate reinforced with a potassic salt, the muriate being used in most cases, and a part this combination of superphosphate and potassic salt, with some carrier of nitrogen added. In some of the Indiana and Kentucky tests, however, all the land has had a basic dressing of manure, thus obscuring the separate effect of the different elements, since manure is an efficient carrier of potassium and nitrogen, though to a less degree of phosphorus.

Effect of potassium on different soils—Omitting these tests, except in the case of superphosphate, the results of experiments made on untreated land, or on land dressed with limestone only are shown in Table XIX, Part III (see Appendix) which shows the increase due to the potassic salt, after subtracting that produced by superphosphate when used alone from that produced by the combination of superphosphate with the potassic salt; this method of comparison being employed because experience has shown that it is only in very rare instances that potassium can be used with profit except when associated with phosphorus.

[4] Computing tobacco at 5 cents per pound of dried crop; wheat, including straw, at $1.25 a bushel, and hay at $12.00 a ton.

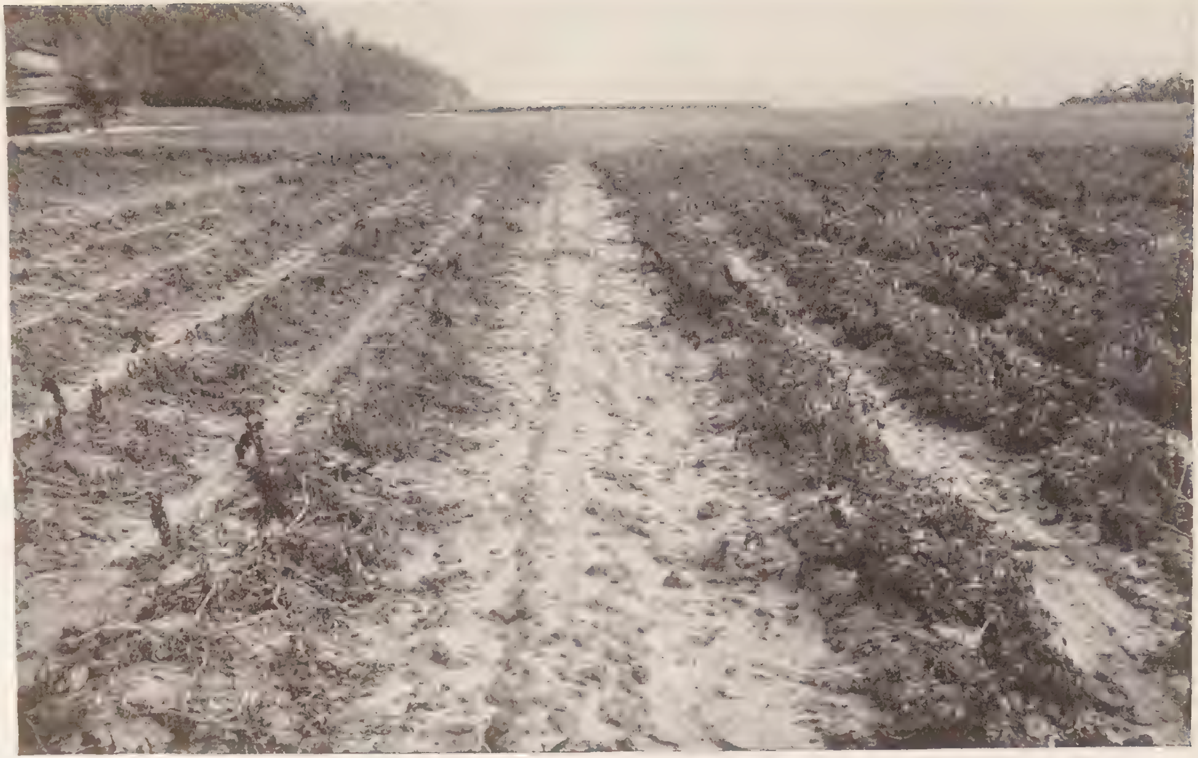

FIGURE IX.—EFFECT OF POTASSIUM ON POTATOES

Effect of potash in prolonging life of potato plant in potatoes-wheat-clover rotation at Ohio Experiment Station. Plot 2, left, superphosphate; Plot 3, right, muriate of potash. Photo by J. Bushnell.

The increases from the potassic fertilizers have been much more irregular than those from superphosphate. In only two of the experiments under consideration has the percentage increase in the entire rotation from muriate of potash exceeded that from superphosphate, namely: the Delaware test and the potato rotation at Wooster. (The corn at Wooster shows a greater increase from potassium than from phosphorus during the later period, but this is overbalanced by the relative increases in the other crops of the rotation.)

It seems evident that the Delaware soil is in greater need of potassium than of phosphorus, and that potatoes and corn may sometimes be more responsive to this element than the cereal crops.

Transposition of effect of phosphorus and potassium—An important feature of the potato rotation is that during the earlier years of the experiment the effects of superphosphate and muriate of potash on the potato crop were similar to those generally observed on other crops—the superphosphate producing the greater increase—but during the later years there has been an increasing tendency to abnormal behavior in the potatoes, the vines dying prematurely where potassium was omitted from the fertilizer and the yield being correspondingly depressed. This outcome is shown in Table XXVII.

TABLE XXVII.—TRANSPOSITION OF EFFECT OF SUPERPHOSPHATE AND MURIATE OF POTASH ON POTATOES. BASIC YIELDS AND INCREASE PER ACRE PER ANNUM BEFORE AND AFTER LIMING.

TREATMENT	*Unlimed* *12 years* *1894-1905*	*After liming* *12 years* *1906-1917*	 *9 years* *1918-1926*
	Bu.	*Bu.*	*Bu.*
Basic yields	169.4	106.2	75.0
Increase: superphosphate alone	18.4	—2.4	—1.6
Muriate potash alone	16.8	26.4	29.8
Superphosphate and nitrate soda	20.9	12.3	15.7
Muriate potash and nitrate soda	8.2	37.2	38.8

No lime has been used on this land since 1915, but the relative increases from superphosphate and muriate of potash are maintained throughout the final period.

This change in the behavior of the potatoes towards phosphorus and potassium began at about the same time as the liming. Unfortunately, it was not practicable to leave any land without lime in this test. Cultural work with potatoes has been conducted on unlimed land, during the same period with the fertility tests, in which the yields have been larger during recent years than under similar treatment in the fertility test, but this cultural work has been shifted from place to place and thus has avoided the cumulative effect of cropping for a long period in so short a rotation as three years.

At the Rothamsted station potatoes were grown continuously on the same land for 26 years, but the yields became so unsatisfactory that the test was discontinued.

It would seem that liming may be unfavorable to the potato, an inference that is supported by the fact that the average yield of potatoes in Ohio, as reported in the State statistics, is about 12 percent greater over the sandstones that are the surface rocks in eastern Ohio than over the limestones that cover the western half of the State. This comparison is complicated, however, by the fact that fertilizers are used more liberally in eastern than in western Ohio.

Liming increases effect of potassium—In the 5-year cereal rotation at Wooster, which is located on land that previously had been under a more exhaustive system of cultivation than that used in the potato rotation, a similar change has taken place in corn grown on limed land, as shown in Table XXVIII which gives the basic yields and the increase from similar treatments to those shown in Table XXVII for the first and last 10-year periods of the 25 years since liming was begun.

On the unlimed land there has been a large reduction in the basic, unfertilized yields, but on the limed land there has been a small increase. During the first 10 years after liming was begun there was but little difference in the effect of the fertilizer on unlimed and limed land, but since that period there has been a marked increase in the effect of the potassic salt on the limed land, with a falling off in that of superphosphate and nitrate, while on the unlimed land there

TABLE XXVIII.—RELATIVE EFFECT OF SUPERPHOSPHATE AND MURIATE OF POTASH ON CORN ON UNLIMED AND LIMED LAND AT WOOSTER. BASIC YIELDS AND INCREASE PER ACRE BY PERIODS.

	Unlimed land		*Limed land*	
TREATMENT	*1904-1913*	*1919-1928*	*1904-1913*	*1919-1928*
	Bu.	*Bu.*	*Bu.*	*Bu.*
Basic yields	22.4	13.9	30.2	31.3
Increase:				
Superphosphate alone	8.6	6.8	8.3	2.7
Muriate potash alone	5.3	4.5	4.3	19.8
Nitrate of soda alone	5.4	6.2	5.1	5.9
Superphosphate, nitrate soda	15.8	17.0	14.9	7.3
Muriate potash, nitrate soda	9.2	8.8	10.3	22.1
Superphosphate, nit. and mur.	21.8	27.2	23.0	26.6

has been comparatively little change. When the three fertilizing materials are combined the reduction in effect of the superphosphate and nitrate is practically compensated by the increased effect of the potassic salt.

This change in the relative effect of the carriers of phosphorus and potassium has been limited to the potatoes and corn grown in the long-continued rotations on the Wooster soil. It has not yet been definitely manifested in any of the other crops grown in these rotations, nor is it shown in the corn and other crops grown on limed land at Strongsville over the same period as at Wooster. The action is apparently a double one—that of a diminishing effect of the superphosphate and an increasing one of the potassic salt, and it seems that this action is exerted chiefly on the crop and not on the soil. It is true that liming has enabled the cereal crops and clover to obtain from the soil more phosphorus, potassium and nitrogen than they were otherwise able to secure, but the investigations of Ames and Simon [5] have failed to reveal any selective effects upon the soil elements due to liming.

The old assumption that lime makes phosphoric acid less soluble might explain the smaller increase from superphosphate on limed than on unlimed land, but a more plausible explanation would seem to be that on these acid soils the basic lime in the phosphate makes it in a small way a carrier of lime as well as of phosphorus, and therefore produces a greater effect on acid soils than that due to its phosphorus alone.[6]

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[5] Ohio Exp. Sta. Bul. 379.

The Delaware test, as has been stated above, is located on a soil exceptionally hungry for potassium. Half the land has been limed for this test, but in the report at hand (Bulletin 137) the results are only given separately for the limed and unlimed land for corn, soybeans and clover. Some of these results are shown in Table XXIX.

TABLE XXIX.—RELATIVE EFFECT OF SUPERPHOSPHATE AND MURIATE OF POTASH AT DELAWARE EXPERIMENT STATION. AVERAGE ANNUAL BASIC YIELDS AND INCREASE PER ACRE

CROP AND TREATMENT	*Basic treatment*	
	None	*Lime*
	Bu.	*Bu.*
Corn: Basic yields	42.9	42.5
Increase: Superphosphate alone	0.2	—1.5
Muriate potash alone	11.9	23.3
Nitrate soda alone	1.2	0.8
Superphosphate; nitrate soda	6.0	1.3
Muriate potash; nitrate soda	24.2	27.7
	Bu.	*Bu.*
Soybeans: Basic yields	12.8	13.3
Increase: Superphosphate alone	2.6	0.5
Muriate potash alone	4.0	8.2
Nitrate soda alone	1.3	0.4
Superphosphate; nitrate soda	4.1	2.3
Muriate potash; nitrate soda	9.8	11.7
	Cwt.	*Cwt.*
Clover: Basic yields	22.9	29.5
Increase: Superphosphate alone	3.0	1.6
Muriate potash alone	1.9	4.2
Nitrate soda alone	2.9	2.0
Superphosphate; nitrate soda	4.1	3.8
Muriate potash; nitrate soda	13.6	14.3

Liming seems not to have increased the basic yield of any crop except clover in this Delaware test, but has produced a marked increase in the effect of the potassium salt.

It will be observed that, while the addition of nitrate of soda to the fertilizer increases the gains in every case it diminishes the difference between the effect of the potash on the unlimed and limed land, due to the fact that the sodium in the nitrate to some extent serves the same purpose as lime. When the further addition of superphosphate is made we find that the total effect is practically the same on unlimed and limed land, and the same is true of manure, as shown by Table XXX, which gives the approximate number of pounds of nitrogen, phosphorus and potassium applied annually per acre in chemicals or manure and the annual increase of corn per acre in the Delaware and Ohio tests.

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[6] In the Kentucky experiments liming has apparently increased the effect of superphosphate. See Table XXIV.

Table XXX.—Effect of Complete Chemical Fertilizers and Manure on Corn on Unlimed and Limed Land. Treatment and Increase per Acre per Annum

Treatment	*Elements* Nitrogen *Lb.*	Phosphorus *Lb.*	Potassium *Lb.*	*Basic treatment and increase* None *Bu.*	Lime *Bu.*
Ohio: 25 years average					
Chemicals	8	6	22	27	27
Chemicals	15	4	22	24	26
Chemicals	22	4	22	28	28
Manure	14	4	11	21	26
Manure	29	7	22	34	34
Delaware: 15 years average					
Chemicals	14	7	7	34	35
Chemicals	28	14	14	41	39
Manure	34	8	26	35	38
Manure	68	16	52	42	42

Tables XXVIII, XXIX and XXX illustrate the inadequacy of partial fertilizing for soils that have been long in cultivation, even where clover is grown in rotation. Whether the purchase of all the elements necessary for complete fertilization is always justifiable requires further consideration.

CONCLUSIONS

The experimental evidence indicates that the requirement of the ordinary field crops for potassic fertilizing is less uniform, and usually less urgent, than that for phosphates, although there are exceptional soils on which the demand for potassium takes precedence over that for phosphorus, and under long continued cultivation there may be a transposition on the same soil in the relative effect of the two elements.

The effect of potassic fertilizers is generally greater on soils derived from limestones than on those derived from shales and sandstones, and the addition of lime to soils of sandstone origin appears to favor the utilization of such fertilizers.

Potatoes and corn are apparently more responsive to potassic fertilizing than wheat, oats or clover, but this difference may become evident only on land that has been limed.

The muriate and sulphate of potash appear to be equally effective, pound for pound of potassium contained.

XIV

Nitrogen

TABLE II, (Chapter V, p. 46) shows that, reckoned in pounds per acre, by far the greatest draft upon the land made by the cereal crops is that of nitrogen, and if it were necessary to purchase and return to the soil all the different elements in the quantities in which they are found in the crop the contrast would be still greater, as shown by Table XXXI, in which the cost of the different elements is computed at approximately their present average cost in Ohio in nitrate of soda, superphosphate and muriate of potash, these being the most effective and usually the cheapest commercial sources of nitrogen, phosphorus and potassium, in condition available to crops.

TABLE XXXI.—REPLACEMENT COST OF CERTAIN CHEMICAL CONSTITUENTS OF AVERAGE CROPS, IN DOLLARS PER ACRE[1]

CROP	*Nitrogen*	*Phosphorus*	*Potassium*	*Lime*	*Total*
Corn	$11.93	$1.83	$1.74	$.20	$15.00
Oats	7.43	.87	1.50	.07	9.87
Wheat	6.53	.72	.90	.05	8.20
Clover	9.68	.56	1.56	.20	12.00
Timothy	4.95	.42	1.50	.05	6.92

It is true that the land never becomes so completely exhausted that it will not produce something without any fertilizing, but on the other hand it is practically impossible to recover in crop increase all the elements applied in fertilizers. These points are illustrated in the following experiments.

Rothamsted experiments—In Broadbalk Field, at the Rothamsted Experimental Station in England, wheat has been grown continuously on the same land since 1843. In 1852 a plan of treatment was adopted which has been continued since. In this plan Plot 3 is left continuously without any manure or fertilizer. Plot 5 receives annually a mixture of 392 pounds superphosphate, 200 pounds sulphate of potash and 100 pounds each of the sulphates of soda and magnesia—a so-called "mineral" fertilizer. Plot 10 receives annually 86 pounds of nitrogen alone, in a mixture of the sulphate and chloride of ammonium. Plots 6, 7 and 8 receive these ammonium salts in quantities carying 43, 86 and 129 pounds of nitrogen, together with the same mineral mixture used on Plot 5, there being no variation in the quantities of minerals used. The average yields and increases for these treatments during the 74 years, 1852-1925, are shown in Table XXXII.

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[1] In this table nitrogen is computed at 22½ cents a pound, equivalent to 18½ cents for ammonia; phosphorus at 15 cents, equivalent to 6.6 cents for phosphoric acid; potassium at 6 cents, equivalent to 5 cents for potash, and lime at one-half cent, prices that would correspond to $70 a ton for nitrate of soda; $21 for 16 per cent superphosphate; $50 for muriate of potash and $10 for quicklime or $5 for ground limestone.

TABLE XXXII.—WHEAT IN BROADBALK FIELD
SEVENTY-FOUR YEARS AVERAGE YIELD AND INCREASE PER ACRE

		Yield		*Increase*	
PLOT		*Grain*	*Straw*	*Grain*	*Straw*
NO.	*Treatment*	*Bu.*[2]	*Lb.*	*Bu.*[2]	*Lb.*
3	None	12.1	1,097	...	....
5	Minerals only	13.9	1,288	1.8	191
10	Nitrogen only (86 lb.)......	19.3	1,993	7.2	896
6	Minerals and 43 lb. nitrogen.	22.4	2,273	10.3	1,176
7	Minerals and 86 lb. nitrogen.	31.4	3,595	19.3	2,498
8	Minerals and 129 lb. nitrogen	35.6	4,457	23.5	3,360

This table strikingly illustrates the importance of adding nitrogen to this soil, which had been under cultivation for centuries before the test was begun. The increase from minerals alone is insignificant. Nitrogen alone, applied at the rate of 86 pounds per acre, has produced four times the increase given by the mineral fertilizers, but when half this quantity of nitrogen is replaced by the minerals the increase is greater than from the full dose of nitrogen, and when the minerals and 86 pounds of nitrogen are combined the increase is ten times that from minerals alone and more than twice that from nitrogen alone, thus demonstrating the necessity for both classes of fertilizing materials. The addition to these minerals of 129 pounds of nitrogen raises the yield to an average of 35.6 bushels of wheat per acre for the 74 years —the largest yield of wheat, considering the duration of the test, of which the world has any record.

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[2] Bushels of 60 lbs.

In "Hoos Field" of the same Station barley has been grown over the same 74-year period, with the outcome shown in Table XXXIII.

TABLE XXXIII.—BARLEY IN HOOS FIELD, ROTHAMSTED
SEVENTY-FOUR YEARS AVERAGE YIELD AND INCREASE PER ACRE

Plot No.	*Treatment*	*Yield* Grain Bu.	*Yield* Straw Lb.	*Increase* Grain Bu.	*Increase* Straw Lb.
1-O	None	13.6	885	...	....
4-O	Minerals only	19.3	1,237	5.7	347
1-A	Nitrogen only (43 lb.)	24.0	1,545	10.4	660
4-A	Minerals and 43 lb. nitrogen	39.9	2,665	26.3	1,780

The mineral fertilizers used in this test are the same in kind and quantity as those used on the wheat, and while their effect on the barley has been somewhat greater than on the wheat, yet it is evident that, with the barley as with the wheat, nitrogen is the dominant element in producing increase in yield.

In "Barn Field" of this English Station mangolds have been grown continuously since 1896. Some of the results, averaged for the 44 years ending 1922—three crops being omitted in the Rothamsted calculations—are given in Table XXXIV.

TABLE XXXIV.—MANGOLDS IN BARN FIELD, ROTHAMSTED
FORTY-FOUR YEARS AVERAGE YIELD AND INCREASE PER ACRE

Treatment	*Yield* Lb.	*Increase* Lb.
None	8,176	.....
Minerals only	10,595	2,419
Nitrogen only	21,728	13,552
Minerals and nitrogen	38,640	30,464

The "minerals" in this test have consisted of 392 pounds superphosphate, 500 pounds sulphate of potash and 200 pounds each of magnesium sulphate and sodium chloride (common salt) all per acre per annum, and the nitrogen is

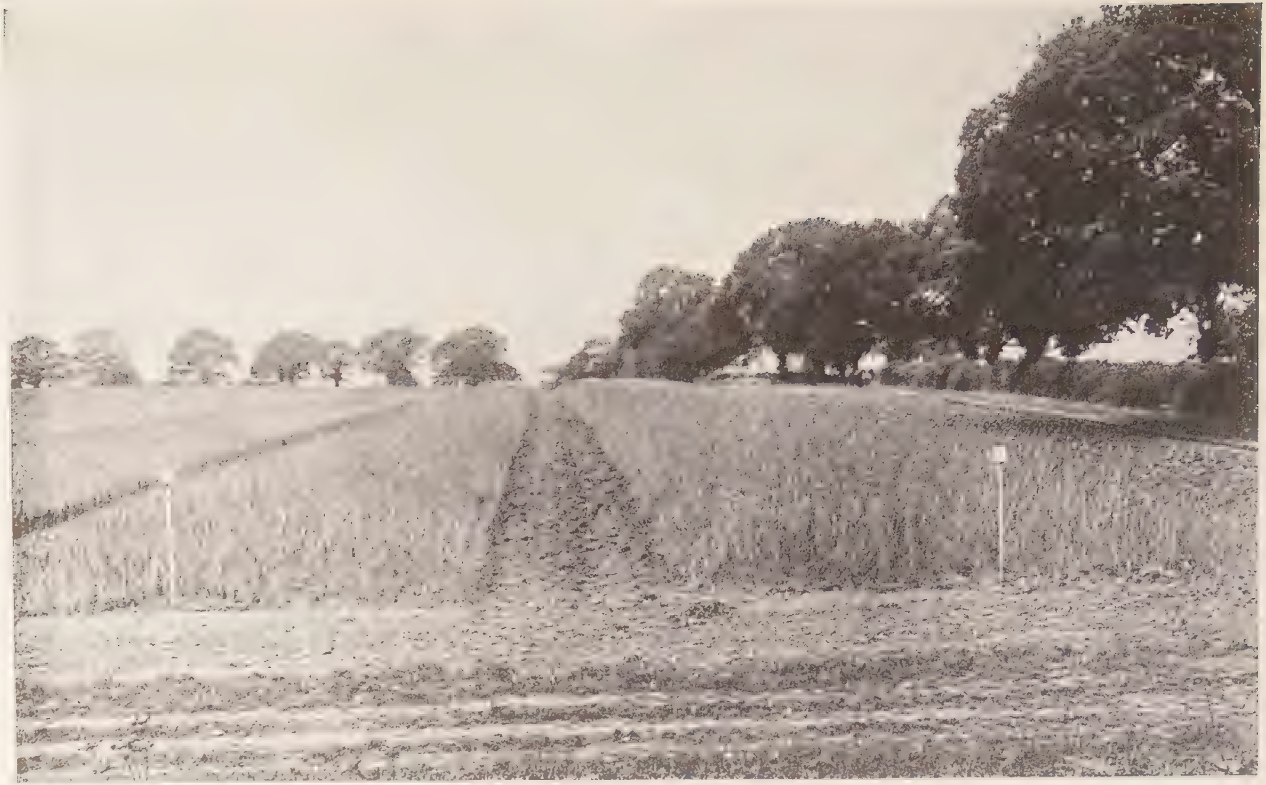

Figure X.—WHEAT IN BROADBALK FIELD, ROTHAMSTED

Rothamsted Experimental Station, Harpenden, England. Broadbalk field, permanent wheat plots, 1913. Plot 2, farmyard manure (on right). Plots 3 and 4, unmanured (on left). Courtesy of Sir E. J. Russell, Director.

given in nitrate of soda at the rate of 86 pounds of nitrogen per acre annually. Evidently, nitrogen is emphatically the major factor in producing increase in this crop, although the support of the mineral elements is essential to its full effect.

Woburn experiments—The Rothamsted Station is located on a heavy clay soil overlying chalk, which had been dug up and spread over the surface many years before the experiments were begun, and in such large quantities that it is estimated that Broadbalk Field must have begun the Nineteenth Century with about 100 tons of chalk per acre in its surface soil.[3] For the purpose of testing, on a soil of very different character, the results that were being attained at Rothamsted a similar series of experiments has been conducted since 1876 at Woburn, about 20 miles northwest of Rothamsted, under the joint auspices of the Royal Agricultural Society of England and the successive Dukes of Bedford, who have provided the land and for many years defrayed the expenses, the scientific direction of the work being successively in charge of Dr. Augustus Voelcker and his son, Dr. J. Augustus Voelcker, Consulting Chemists of the Royal Agricultural Society. Since 1921 the wheat and barley experiments have been conducted by the Rothamsted Station, with Dr. Voelcker as Honorary Local Director.

The land selected for these experiments is "a light, sandy loam of reddish color, situated on the Lower Greensand formation." After the experiments had been in progress for 20 years the yields began to fall off on the land receiving ammonium salts. Fortunately, nitrate of soda had been used as a duplicate nitrogen carrier from the beginning, and in Table XXXV the yields given are for the treatment with nitrate of soda.

In this experiment the "minerals" have consisted of 336 pounds of superphosphate and 56 pounds of sulphate of potash. Nitrogen has been given at the rate of 41 pounds per acre for 30 years and in half that quantity since. The highest rate of fertilizing has been below the lowest rate at Rothamsted, and the reduction in rate of treatment at the end of 30 years has been followed by a considerable reduction in

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[3] Hall, A. D., "Book of the Rothamsted Experiments." Edition of 1905, p. 28.

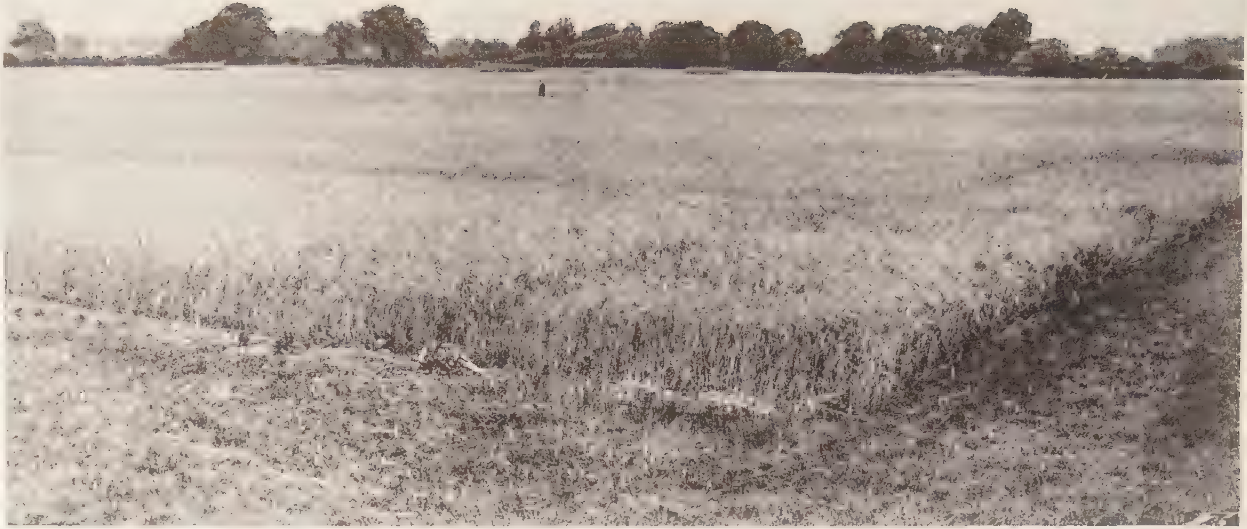

Figure XI.—BARLEY IN HOOS FIELD, ROTHAMSTED

Rothamsted Experimental Station, Harpenden, England. Hoos field, permanent barley crops, harvest of 1913. Courtesy of Sir E. J. Russell, Director.

TABLE XXXV.—WHEAT AND BARLEY AT WOBURN
FORTY YEARS AVERAGE YIELD AND INCREASE PER ACRE

TREATMENT	*Wheat* *Yield* *Bu.*[4]	*Wheat* *Increase* *Bu.*[4]	*Barley* *Yield* *Bu.*[5]	*Barley* *Increase* *Bu.*[5]
None	13.0	...	16.0	...
Minerals only	12.2	—.08	18.5	2.5
Nitrogen only............	21.1	8.1	27.5	11.5
Minerals and nitrogen....	26.7	13.7	35.5	19.5

yield. The outcome, however, is in harmony with that at Rothamsted in that nitrogen has been the dominant factor in producing increase in yield.

Ohio experiments—At the Ohio Experiment Station corn, oats and wheat have been grown continuously since 1894; one acre, subdivided into 10 plots, being given to each crop. Every third plot is left continuously unfertilized, and the treated plots are compared with the unfertilized plots between which they lie—not with the general average of all the untreated plots—this method of comparison eliminating in part the differences due to irregularities of soil.

Plot 2 for each crop receives annually 25 pounds of nitrogen in nitrate of soda, together with 11.2 pounds of phosphorus in superphosphate and 41 pounds of potassium in muriate of potash. Plot 8 receives the same quantities of superphosphate and muriate of potash as Plot 2, but the nitrate is doubled. Plot 3 receives the same quantity of nitrogen as Plot 2, but the phosphorus and potassium are reduced to the same ratio to 25 pounds of nitrogen in which they are found in the plant, and on Plot 9 the entire dressing given to Plot 3 is doubled. Plots 5 and 6 are manured.

This scheme of fertilizing makes it possible to determine the increase due to 50 pounds of nitrogen over that given by 25 pounds and the increase due to the larger dressings of phosphorus and potassium combined on Plots 2 and 8 over the smaller ones on Plots 3 and 9, after the plan given in Table XXXVI, which shows the method of calculation.

By the same method of calculation the gain for one pound of the mixed minerals is 0.2 bushel of oats and 0.1 bushel of

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[4] Bushels of 60 pounds. [5] English bushels.

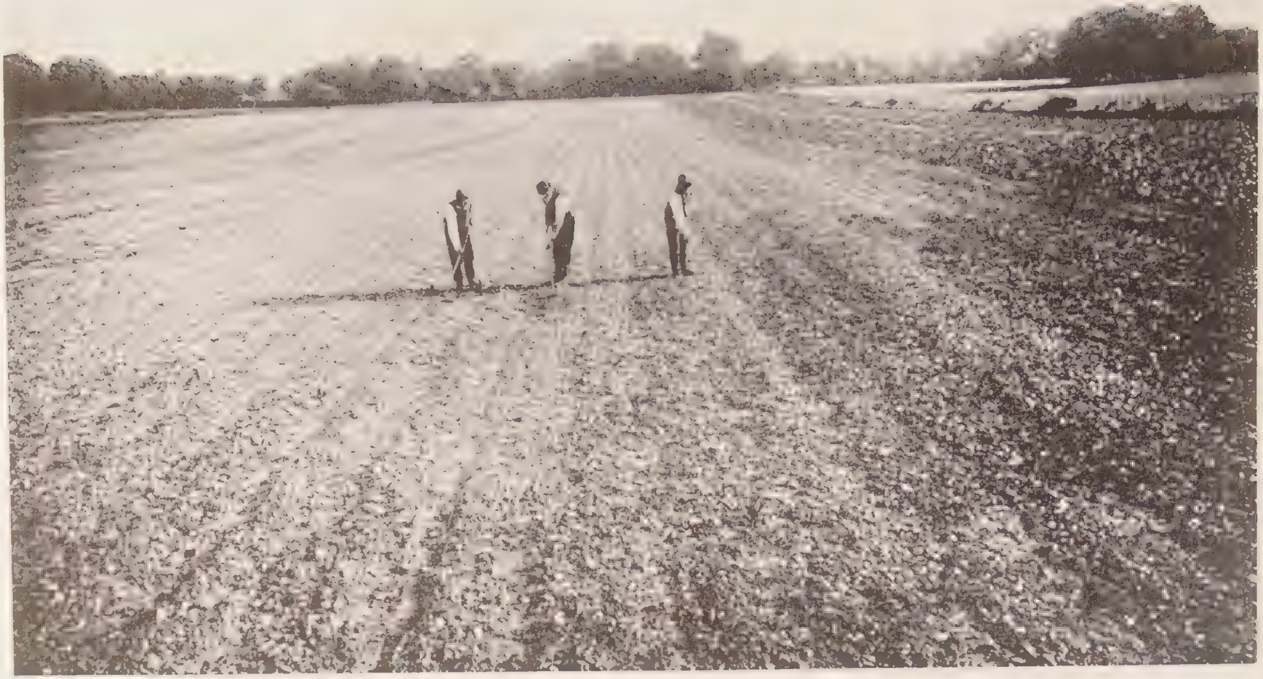

Figure XII.—PERMANENT ROOT PLOTS, BARN FIELD, ROTHAMSTED

Rothamsted Experimental Station, Harpenden, England, Barn field, permanent root plots, 1915. Strips 1 and 2, manure only; and manure, superphosphate and potash, respectively, shown on extreme right of picture. Courtesy of Sir E. J. Russell, Director.

Table XXXVI.—Corn Grown Continuously at Ohio Experiment Station Thirty Years Annual Treatment and Average Increase per Acre

	Plot	*Composition of fertilizer*			*Increase per acre*
	No.	*Nitrogen Lb.*	*Phosphorus Lb.*	*Potassium Lb.*	*Bu.*
	2	25	11.2	41	21.81
	8	50	11.2	41	32.75
Gain for nitrogen.........	..	25	...	..	10.94
	2	25	11.2	41	21.81
	3	25	4.2	12	16.17
Gain for minerals.........	..	..	7.0	29	5.64
	8	50	11.2	41	32.75
	9	50	8.4	24	30.55
Gain for minerals..........	..	..	2.8	17	2.20
Average gain for minerals..	..	..	4.9	23	3.42
Gain for 1 lb. minerals....	..	..	..	..	.14
Gain for 1 lb. nitrogen....	..	..	..	..	.44

wheat, and that for one pound of nitrogen is 0.2 bushel of oats and 0.13 bushel of wheat.

These comparisons are defective in that they do not show the first effect of the fertilizer. Referring to Table XXXIII it will be seen that at Rothamsted the first installment of 43 pounds of nitrogen increased the yield by 10.6 bushels; the second by 9 bushels and the third by 4.5 bushels—an outcome in harmony with the law of diminishing returns, which is that the gain per unit of fertilizer becomes relatively smaller as the quantity of fertilizer is increased. They show, however, that, on the Ohio, as on the English soil, the nitrogen supply is a leading factor in producing increase in the crops thus far considered.

Effect on potatoes and tobacco—Two crops belonging to a different botanical order from those we have been studying have been subjected to continuous culture for considerable periods of time. At Rothamsted potatoes were grown continuously for the 26 years, 1876-1901, and at the Germantown farm of the Ohio Experiment Station tobacco has been grown continuously since 1903.

In the potato test a mineral fertilizer, containing 152 pounds of phosphorus and potassium combined, increased the yield by 57.5 bushels, or 0.37 bushel for each pound of the combination, while 86 pounds of nitrogen in nitrate of soda, when used alone, increased the yield by 28.2 bushels, or 0.33 bushel for one pound of nitrogen. Where the mineral and nitrogenous dressings were combined the increase was 151.8 bushels, or nearly double the sum of the increases from the separate dressings.

In the tobacco test a combination of 11 pounds of phosphorus, 25 pounds of potassium and 12½ pounds of nitrogen has given an average annual increase for the 24 years, 1903-1926, of 337 pounds of tobacco. Adding 12½ pounds of nitrogen to the fertilizer has caused a further increase in yield of 75 pounds, or 6 pounds of tobacco for one pound of nitrogen. A further addition of 25 pounds of nitrogen has given an additional increase of 124 pounds of tobacco, or 5 pounds of tobacco for one pound of nitrogen, but when a third increase of nitrogen is made there is no further gain in yield until the mineral elements in the fertilizer are increased.

The nitrogen and potassium remaining unchanged, an increase of 11 pounds of phosphorus has increased the yield by 129 pounds of tobacco, or nearly 12 pounds of tobacco for one pound of phosphorus, and the nitrogen and phosphorus remaining stationary, an increase of 25 pounds of potassium has raised the yield by 55 pounds of tobacco, or nearly 2 pounds of tobacco for one pound of potassium. It appears, therefore, that phosphorus has been much the most important factor in producing increase in yield of tobacco.

The plan of fertilizing in this experiment, as in the continuous culture of corn, oats and wheat at Wooster, does not reveal the first effect, either of the nitrogenous or of the mineral constituents of the fertilizer, taken separately, but it is evident that these two groups play different roles with respect to each other in these solanaceous crops from those shown in the Gramineae.

It is a common observation that wheat gives larger yields after potatoes or tobacco than after gramineous crops, and Welton and Morris, of the Ohio Experiment Station, have furnished an explanation of this fact by investigations which show that there is usually a larger accumulation of nitrates in the soil after a crop of potatoes has been grown than after corn or oats, or even after soybeans.[6]

Recovery of nitrogen—In Table XXXVII is shown the quantities of total mineral elements and of nitrogen applied in the fertilizers in these experiments in continuous culture of cereal crops and mangolds, the estimated recovery of nitrogen in the increase of crop produced, based upon average analyses of such crops, and the percentage which this recovery constitutes of the total quantity given in the fertilizer.

Table XXXVII.—Nitrogen Balance Sheet of Experiments in Continuous Culture

		Fertilizer		*Nitrogen recovery*	
Crop and Station	*Plot*	*Nitrogen*	*Minerals*[7]	*Total*	*%*
Wheat		*Lb.*	*Lb.*	Lb.	%
Rothamsted	6	43	112	18	42
	7	86	112	33	39
	8	129	112	41	32
Woburn	6	41	46	23	57
Ohio	2	25	52	22	88
	3	25	15	14	56
	8	50	52	29	58
	9	50	30	25	50
Barley					
Rothamsted	4-N	43	112	33	74
Woburn	6	41	46	24	59
Oats					
Ohio	2	25	52	20	80
	3	25	25	15	61
	8	50	52	25	50
	9	50	49	23	46
Corn					
Ohio	2	25	52	30	120
	3	25	16	22	87
	8	50	52	44	89
	9	50	32	41	82
Mangolds					
Rothamsted	4-N	86	233	61	71

This balance sheet shows that the recovery of nitrogen is conditioned in part upon the quantity of nitrogen given, in part upon the supply of available mineral elements, and in part upon the crop, and that only in exceptional cases have these three factors been so coordinated as to result in the recovery in increase of crop of as much as three-fourths of the nitrogen given in the fertilizer.

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[6] Jour. Am. Soc. Agrom. 16: 519-534.

[7] Phosphorus and potassium.

With increasing amounts of nitrogen in the fertilizer at Rothamsted the total recovery increases, but the percentage diminishes, although the recovery never reaches half the quantity given. In these tests the minerals have been supplied more liberally than in either of the others.

At Woburn both the nitrogen and the minerals have been reduced, and the recovery is a little greater in wheat but smaller in barley than from the 43-pound dressing at Rothamsted. The Woburn experiment, however, has not been running so long as that at Rothamsted, and the plots selected for comparison at Woburn have received their nitrogen in nitrate of soda, whereas the carrier at Rothamsted has been sulphate of ammonia. This point will be discussed more fully in another place (see Chapter XIX). It is sufficient here to say that it is necessary in this comparison to use the nitrate carrier at Woburn because the crops there have ceased to grow on the land dressed with sulphate of ammonia unless lime also is added, whereas at Rothamsted the difference in effect of the two carriers is not large and the nitrate was not used in the earlier years of the test.

In the Ohio tests the smaller dressing of nitrogen is less than that given in either of the English tests, and where it is liberally supported by the mineral elements nearly 90 percent of the nitrogen given to wheat is accounted for in increase of crop. Doubling the nitrogen in the fertilizer without increasing the minerals gives a larger total return but a smaller relative one, the increase containing less than 60 percent of the nitrogen given in the fertilizer. Reducing the mineral support reduces the increase with both the smaller and the larger dressings of nitrogen, and thus causes a waste of the costliest constituent of the fertilizer.

In all of the Ohio experiments with wheat the percentage recovery of nitrogen is greater than the highest at Rothamsted, the average being slightly above that at Woburn. The Ohio tests, however, have been running for a shorter period than either of the English tests.

In the two barley tests it seems probable that the difference in outcome is due chiefly to the more liberal mineral treatment at Rothamsted than at Woburn.

In the Ohio tests the outcome with oats is very similar to that with wheat. Corn, however, has shown a larger return of nitrogen than either of the small grains, the recovery on Plot 2 being larger than the amount given in the fertilizer, and as large as that amount plus the estimated annual addition to the land of the nitrogen brought down in rain and snow. But it cannot be possible to recover in the harvested portion of the crop all the nitrogen added to the land, for the stubble and roots will consume nitrogen, some of which will be lost in the transformations necessary to reconvert it into available form.

A probable explanation of the larger recovery of nitrogen in corn is that this crop grows under just the conditions essential to the bacterial action, by which the organic nitrogen of the soil is converted into available form, growing as corn does during hot, summer weather, and the soil in which it grows being stirred occasionally by cultivation.

If the larger return of nitrogen in the corn crop is due to a more complete utilization of the store of organic nitrogen in the soil through nitrification, we should expect to find a relatively greater reduction in the yield of corn under continuous culture than in that of the small grains, and this is what has actually occurred.

Maintaining the yield in continuous culture—A question of fundamental importance in this problem is whether any of the treatments given are maintaining the yield of the land. This point will be discussed in the next chapter.

CONCLUSIONS

The experiments reported in this chapter show that, if crops are grown continuously without the intervention of any nitrogen accumulating crop, the time ultimately arrives when nitrogen, as well as the mineral elements, must be restored to the land in approximately the ratio to each other in which they are found in the harvested portions of the crop, if the yield is to be maintained without impoverishment of the soil.

They also show that a liberal supply of available phosphorus and potassium is essential to the economical utilization of nitrogen, and that, in the case of other field crops than corn, considerably less nitrogen will be recovered in the increase of crop than has been given in the fertilizer, the exception in the case of corn being apparently due to the fact that the conditions under which this crop is grown favor the nitrification of the organic matter of the soil.

XV

Maintaining the Yield in Single Cropping

Specialization in agriculture—The general tendency in modern industry is towards specialization. The workman who confines himself to the making of a single part of an elaborate mechanism will become more expert in the making of that part than if he were to construct the entire machine; the merchant who limits his trade to a single line, as groceries, or drugs, or drygoods, or shoes, can obtain a much better knowledge of the factors that enter into the profitable handling of his specialty than the one who keeps a general store. Even in the great department stores this principle is fully recognized, by placing specialists in charge of the different departments.

It would seem, at first thought, that this principle might apply equally to farming, especially as certain soils are naturally better adapted to certain crops than to others, and in some regions this system is actually in practice. In the southern states there are extensive areas where cotton is the only crop grown; in others the one crop is sugar cane; in others, rice. When the vast prairies of the Red River Valley of Minnesota, Dakota and Manitoba were brought under cultivation the soil and climate were found to be exceptionally adapted to wheat, and wheat became practically the exclusive crop in that region. In many fields in the bottom lands of rivers corn has been grown continuously for an indefinite period.

The convenience of single cropping—There is much to be said in favor of this system. It permits the most perfect adaptation of the crop to natural soil and climatic conditions; it does not require so large an investment in implements as where general farming is followed; it facilitates the oversight of labor, as it is easier to train laborers to do one thing than to do many different things; it simplifies the marketing problem, there being but one product to be sold, and that being produced in such large quantity that the expense of marketing is reduced by the lower freight rates on carloads than on smaller quantities.

The disadvantage of single cropping—But with all these advantages there are some fatal defects in the single cropping system. In the first place, it does not permit the most economical distribution of labor. This does not apply to the cotton crop to so great an extent as to wheat and corn, as cotton is grown under climatic conditions which permit the planting and harvesting to be extended over considerable periods of time, so that as soon as the final picking is completed the plow may be started in preparation for the succeeding crop; but in northern latitudes the planting periods are relatively short, and although the planting, cultivation and harvesting of the corn crop permit the distribution of labor over the larger part of the year, with the wheat crop the labor is all expended in two relatively short seasons and during the larger part of the year the crop requires no attention, consequently the laborers, after having sown the wheat, must seek other employment for several months until the crop is ready to harvest, and they are again without employment for several months through the winter.

But the chief objections to single cropping are based on the fact that under this system it will be necessary to furnish enough available nitrogen, as well as mineral elements, to replace that removed by the crops, and the assumption that single cropping may increase the liability to attack from insects and fungous diseases, and thus make it more difficult to maintain the yield. The experiments considered in the previous chapter have been continued long enough to throw some light upon this point of maintenance of yield, and for this purpose the results of the English and Ohio tests are arranged in Table XXXVIII by periods, the Rothamsted yields being averaged in three periods of 20 years each and a final one of 15 years, those at Woburn in four ten-year periods, and the Ohio test in three periods of 10 years each and a final one of five years.

Table XXXVIII shows that in Broadbalk Field an annual dressing of 15½ tons of manure or of chemicals containing 129 pounds of nitrogen has maintained the yield of wheat for 60 years at a very high level. Whether the falling off during the last 15 years is to be a permanent reduction or is merely due to temporary seasonal conditions is for the future to disclose. Evidently it would be a calamity to science if this test were discontinued at the present stage. Whatever the cause, it appears to be having practically the same effect on the manured wheat as on that fertilized with chemicals.

Table XXXVIII.—Maintenance of Yield in Continuous Culture

Station	*Crop*	*Treatment per acre per annum*	*Period and annual yield per acre*			
			I	*II*	*III*	*IV*
			Bu.	*Bu.*	*Bu.*	*Bu.*
Rothamsted	Wheat	None	15.2	11.5	11.6	7.4
		Minerals	16.9	12.9	14.1	8.7
		Minerals & 43 lb. nitrogen	26.4	21.8	22.2	14.2
		Minerals & 86 lb. nitrogen	35.3	30.9	31.4	20.9
		Minerals & 129 lb. nitrogen	38.3	34.8	37.8	24.1
		Manure, 15½ tons	35.8	33.4	36.9	24.5
Rothamsted	Barley	None	19.9	13.2	9.6	10.5
		Minerals	27.4	17.3	14.3	17.3
		Minerals & 43 lb. nitrogen	49.7	41.3	37.4	33.4
Woburn.....	Wheat	None	17.1	13.6	9.7	9.9
		Minerals	17.7	12.6	8.2	8.6
		Minerals & 41 lb. nitrogen [1]	32.4	30.1	23.6	17.5
Woburn.....	Barley	None	24.9	17.5	12.5	9.2
		Minerals	23.3	21.7	16.2	12.7
		Minerals & 41 lb. nitrogen [1]	40.4	30.9	23.7	17.8
Ohio........	Corn[2]	None	21.5	12.0	9.9	10.2
		Minerals & 25 lb. nitrogen	45.9	38.4	33.4	30.9
		Minerals & 50 lb. nitrogen	49.5	47.2	39.3	41.4
Ohio........	Oats	None	24.3	20.0	17.2	18.8
		Minerals & 25 lb. nitrogen	41.2	40.0	37.0	48.2
		Minerals & 50 lb. nitrogen	48.8	44.3	44.9	62.4
Ohio........	Wheat[2]	None	9.2	5.8	6.8	7.9
		Minerals & 25 lb. nitrogen	20.8	17.3	19.3	17.8
		Minerals & 50 lb. nitrogen	23.0	21.5	22.8	21.6

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[1] 20½ pounds during last period.

[2] Land limed since the first period.

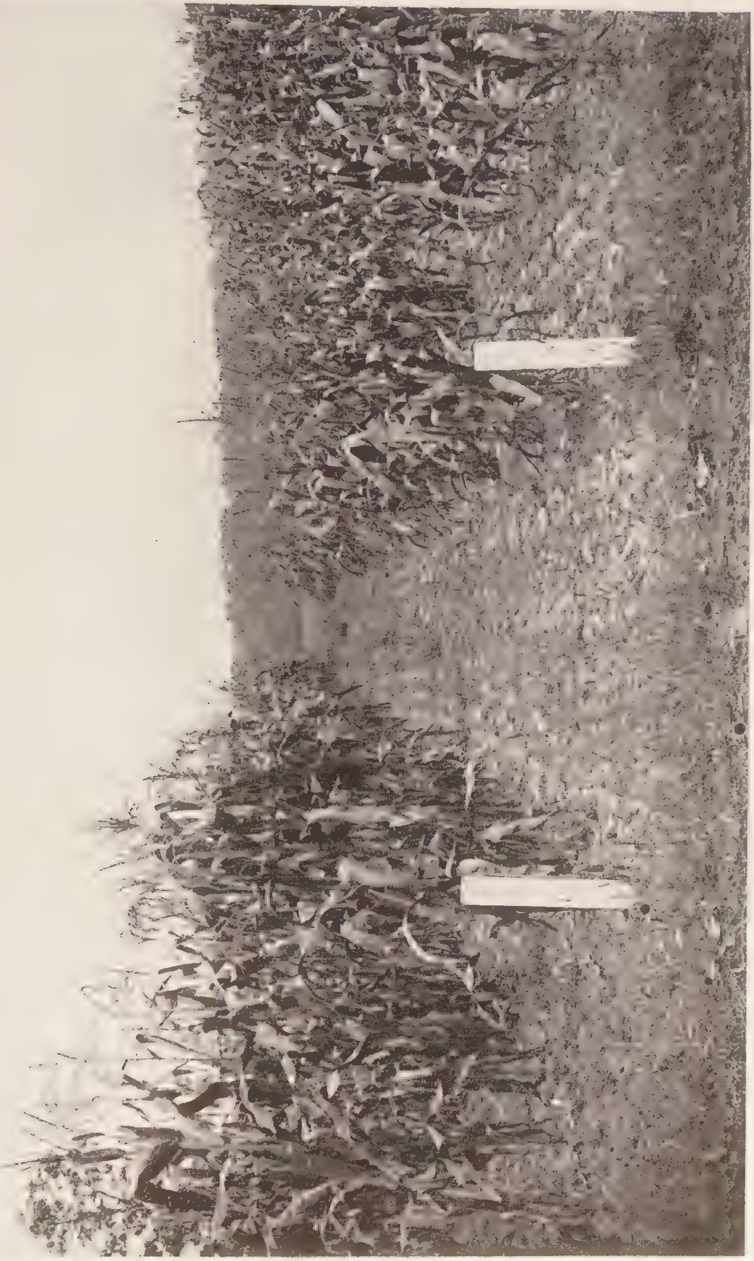

FIGURE XIII.—CORN IN CONTINUOUS CULTURE, OHIO EXPERIMENT STATION

Plot 6, left, 5 tons manure. Plot 7, right, no treatment.

Decreasing the amount of nitrogen in the fertilizer has in every case resulted in diminished yields, and when nitrogen is withheld altogether the yield falls to a level but little above that of the land receiving neither fertilizer nor manure.

At Woburn the manure and chemicals have been used in smaller quantities than at Rothamsted, and the yields are correspondingly lower, although the yield of the unfertilized land has been a little larger. The results given in the table are for the part of the test in which nitrate of soda has been used as the carrier of nitrogen, since on the Woburn soil sulphate of ammonia has almost completely destroyed the crops when used in the absence of lime. (See Fig. 20.)

At Woburn, as at Rothamsted, every reduction of nitrogen in the fertilizer has been followed by diminished yield of wheat, and when the nitrogen is completely withheld the yield from the minerals falls below that of the unfertilized land. None of the Woburn treatments has fully maintained the yield through the first 30 years of the test.

The Ohio experiment is located on land considerably below that of either of the English tests in natural fertility, as indicated by the untreated yields, and the manure and chemicals have been used in much smaller quantities. The table indicates that the yields of the fertilized wheat have been nearly maintained throughout the 35 years, although at a low level, but this result has been largely due to the liming of the land since the first period. The reduction of nitrogen has been followed here as in the English tests by diminished yield, but no provision was made here for the use of the mineral fertilizers in the absence of nitrogen.

In the barley tests nitrogen has been given only in the smaller quantities of 43 pounds per acre at Rothamsted and 41 pounds at Woburn, and its record is that of a progressive reduction in yield. When the nitrogen is withdrawn altogether there is a further reduction in yield, although not so great as in the similar treatment of wheat.

The yield of oats has been practically maintained in the Ohio test, the yield from 50 pounds of nitrogen being a little larger during the last period than during the first, but the corn shows a rapid falling off in all the treatments except

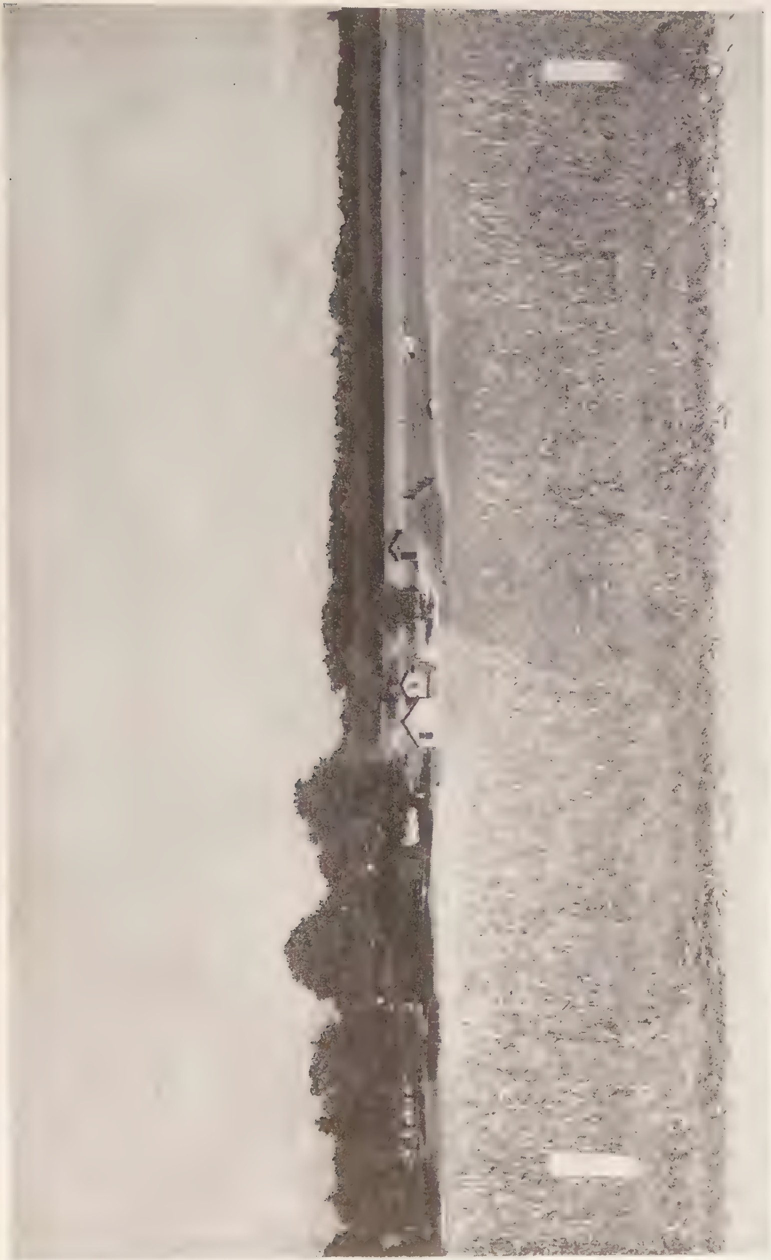

FIGURE XIV.—WHEAT IN CONTINUOUS CULTURE, OHIO EXPERIMENT STATION

Plot 3, left, complete fertilizer. Plot 4, right, no treatment. Plot 5, extreme right 2 1-2 tons manure. 1927.

during the last short period, and where the land has been left without any reinforcement the value of the crop is far below the cost of its cultivation.

It is true that on some of the rich bottom lands of Ohio corn has been grown continuously for long periods without apparent reduction in yield, but this has been accomplished by the aid of occasional overflows, which have left behind a thin coating of silt, containing the cream of the fertility of the higher land adjoining the streams—a process which has made all the more necessary the systematic reinforcement of these uplands, which constitute probably more than 90 percent of the State's area.

The cereal crops have been grown continuously over long periods by the Indiana, Illinois and Missouri experiment stations, but the published records do not furnish satisfactory data for comparing the results by periods, hence they have been omitted from the present discussion.

Cost of maintaining yield in single cropping—Assuming that the falling off in yield of the English tests may be due to temporary seasonal conditions, or to lack of lime, one or both, let us count the cost of maintaining yield under continuous cropping on the Wooster soil. Since the maintenance of the supply of the mineral elements is as essential in rotative as in continuous cropping, we will consider the cost of the nitrogen only. At 22½ cents a pound, 50 pounds of nitrogen would cost $11.25. This expenditure, made annually per acre, has failed to maintain the yield of corn, although it has increased the yield during the last period over that of the rapidly declining yield of the unfertilized land by 31 bushels per acre, at a cost of about 36 cents a bushel. The yield of oats has been well maintained by this treatment, the average over the unfertilized yield for the 35 years being 28 bushels, costing 40 cents a bushel. The yield of wheat has also been maintained, the increase for the 35 years being 15.7 bushels, costing 70 cents a bushel. These final yields are all higher than the average yields of the State, and if there were no cheaper source of nitrogen than chemicals the expenditure might be justified, but let us look for cheaper nitrogen.

XVI

The Search for Cheaper Nitrogen

Continuous vs. Rotative Cropping—For centuries farmers have observed that other crops thrive exceptionally well when preceded by clover, and the earlier chemists believed that clover was able to obtain its nitrogen directly from the atmosphere by absorption through its foliage, just as all plants get their oxygen and carbon. It was not until the eighth decade of the Nineteenth Century that this belief was overthrown by the rigorous work of the Rothamsted Experiment Station; but while this work was in progress the methods of the new science of bacteriology, applied by German investigators, revealed the fact that clover and other leguminous plants do secure nitrogen from sources unavailable to other plants; not, however, through their foliage but by the aid of the organisms that form the nodules found on their roots, and which are able to assimilate the free nitrogen of the air circulating in the upper layers of the soil.

Crop rotation in Agdell Field—Parallel to its experiments in continuous cropping, the Rothamsted Station has conducted a 4-year rotation in which Swede turnips, barley, clover or beans, and wheat, have been grown in the order named since 1848. Clover has been subject to disease on that old farm, and when it has failed beans have been grown instead, which has been more than half the time.

There is but one series of plots in this field, so that each crop has been grown only every fourth season, but the test has been continued so long that the factor of seasonal variation becomes less important.

In this rotative cropping part of the land receives no fertilizer nor manure; part receives a mineral dressing, consisting of 392 pounds superphosphate, 500 pounds sulphate of potash, 100 pounds sulphate of soda and 200 pounds sulphate of magnesia, and a third part receives the same mineral dressing, together with 200 pounds ammonium salts and 2,000 pounds rape cake, the whole carrying about 140 pounds of nitrogen.

The treatment is all applied to the turnips, hence the grain crops receive no direct fertilizing. The nineteenth complete rotation was completed in 1925, and Table XXXIX gives the yields of 19 rotated crops each of wheat and barley grown in this field, in comparison with 74 crops of each grain grown continuously in Broadbalk and Hoos fields.

TABLE XXXIX.—COMPARISON OF CONTINUOUS AND ROTATIVE CROPPING AT ROTHAMSTED. AVERAGE ANNUAL YIELDS PER ACRE

CROP AND TREATMENT	*Cropping and yield*	
	Continuous	*Rotative*
	Bu.	*Bu.*
Wheat: Untreated	11.7	22.8
Minerals only	13.5	31.2
Minerals and nitrogen	34.5	31.2
Barley: Untreated	13.6	20.9
Minerals only	19.3	27.9
Minerals and nitrogen	39.9	36.8

On the untreated land rotation alone has nearly doubled the yield of wheat and has added more than 50 percent to that of barley. The minerals used alone have had little effect on the continuously grown wheat, but have nearly trebled the yield of that grown in rotation, as compared with that grown continuously on untreated land.

With barley, the minerals used alone have produced a larger increase than with wheat, and have doubled the yield of the rotated barley, as compared with that grown continuously, but untreated.

The addition of 129 pounds of nitrogen every year to the minerals has practically trebled the yield of the continuously grown wheat, while 140 pounds of nitrogen, given every fourth year to the previous turnip crop, has added nothing to the rotated wheat beyond the yield produced by the mineral dressing.

With barley, however, 43 pounds of nitrogen added to the minerals has trebled the yield of the continuously grown crops, while the yield of the rotated barley receiving 140 pounds of nitrogen added to the minerals has fallen 3 bushels

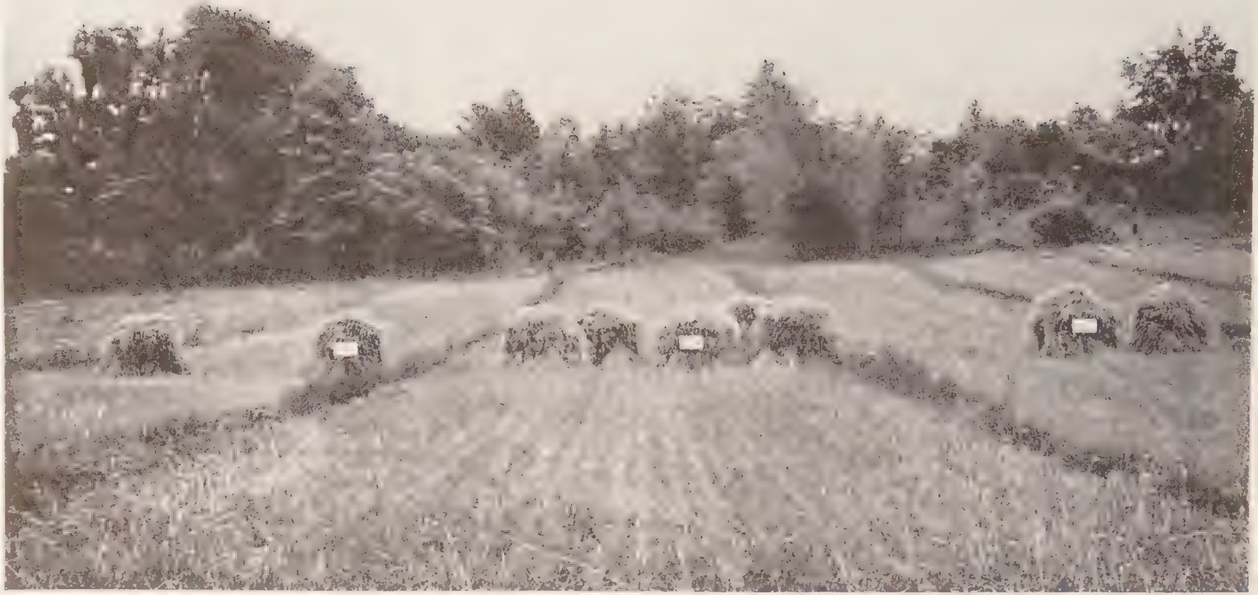

FIGURE XV.—WHEAT AT PENNSYLVANIA EXPERIMENT STATION

Plot 4 (left) potassium only; Plot 5 (middle) phosphorus and nitrogen; Plot 6 (right) nitrogen and potassium. Courtesy of R. L. Watts, Director and F. D. Gardner, Agronomist.

short of that grown continuously with the smaller nitrogen dressing.

Rotation saves nitrogen—It is evident that rotation has to a considerable extent supplied the demand of these grain crops for nitrogen, and that, as used in these experiments, the addition of nitrogen to the fertilizer has been much less effective with the rotated than with the continuously grown crops. As has been stated, in Agdell Field the fertilizers are all applied to the turnips, the barley and wheat following without any further treatment. Apparently the barley, following immediately after the turnips, has profited to some extent by the nitrogen given to the turnips, but the wheat, two years later, has not. This evanescent effect of nitrogenous fertilizers is shown in Plots 17 and 18 of Broadbalk Field, which receive a mineral fertilizer alone one year and ammonium salts alone the next, the two treatments alternating. The outcome has been an average yield for the 74 years of the test of 14.1 bushels per acre for the minerals following nitrogen, or about half a bushel more than that of the land receiving minerals only, as against 27.8 bushels for the nitrogen dressing, or 9 bushels more than that given by the land receiving the same quantity of ammonium salts alone every year, and only 2.6 bushels less than that from the combined minerals and ammonium salts, applied every year. The effect of the minerals has therefore extended forward into the following season, whereas that of the nitrogen has been practically limited to the season of application.

It is evident from these experiments that large crops may be grown for a long period of time in continuous culture, but the economy of this practice is another question. If the other crops grown in Agdell Field have paid their share of the cost of the fertilizer, then the charge for nitrogen against the wheat or barley crop will be one fourth of 140 pounds, or 35 pounds, as against 129 pounds in the continuous cropping. This would leave a charge of 94 pounds, costing $20 or more, against the excess of 3.3 bushels of wheat or 3.1 bushels of barley harvested in the continuous, over the rotative cropping.

American experiments—Experiments in continuous, as compared with rotative cropping, were begun at the Univer-

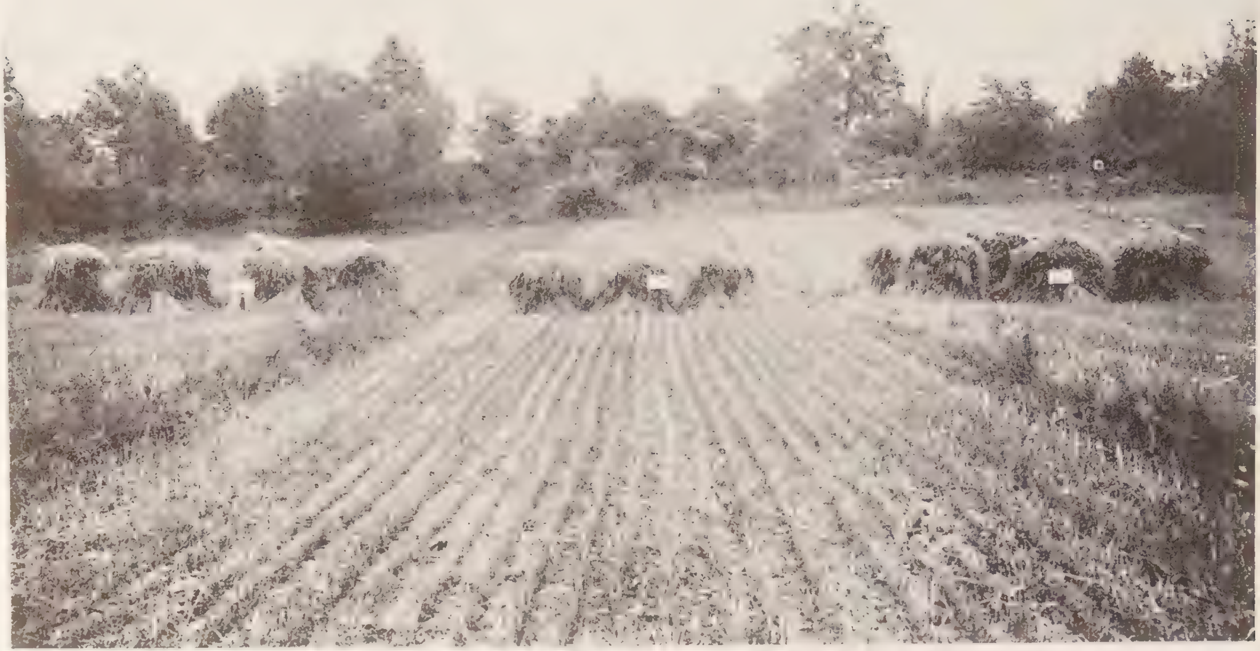

FIGURE XVI.—WHEAT AT PENNSYLVANIA EXPERIMENT STATION

Plot 7 (left) phosphorus and potassium; Plot 8 (middle) nothing; Plot 9 (right) phosphorus, potassium and nitrogen. Courtesy of R. L. Watts, Director, and F. D. Gardner, Agronomist.

sity of Illinois in 1879 and at that of Missouri in 1889 and have been continued by the experiment stations of those states. Similar tests were begun by the Ohio Experiment Station in 1894.

In the Illinois experiments the comparison was limited to corn, and no record of crop yields is available for the first 8 years. For the 30 years following, the average yield per acre for corn grown every year on the same land without any treatment was 34 bushels; for corn grown alternately with oats, the yield was 41 bushels, and for corn grown in rotation with oats and clover it was 50 bushels, the soil being the dark brown prairie loam of the University farm at Urbana.[1]

The larger yield of corn, when grown alternately with oats, is explainable on the assumption that the intervening oats crop, being a smaller consumer of nitrogen than corn, has left a larger residue of organic nitrogen in the soil to be made available to the succeeding crop than corn would have done. The growth of the oats crop ends by the first of August, leaving a month to six weeks of weather suitable for soil nitrification, a period during which corn makes a large part of its growth, thus consuming the nitrogen that is held in reserve, either in the roots and stubble of the oats or in the weeds that grow in the stubble, all to be plowed under the following spring for corn. Taking the average figures given in Table II (page 46) two crops of corn, grown in succession, would contain 105 pounds of nitrogen, as against 86 pounds found in one crop of corn and one of oats.

At the Ohio Experiment Station corn, oats and wheat have each been grown continuously and all in succession in a 5-year rotation of corn, oats, wheat, clover and timothy since 1894, each crop in the rotation being grown every year. In Table XL some of the results of this work are arranged for comparison.

Table XL shows that notwithstanding the smaller supply of the mineral elements, and without any nitrogen except that furnished by the clover and such residues of stubble and roots as were not consumed by the preceding crops in the

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[1] Compiled from Bul. 219, Ag. Exp. Sta., Univ. of Il.

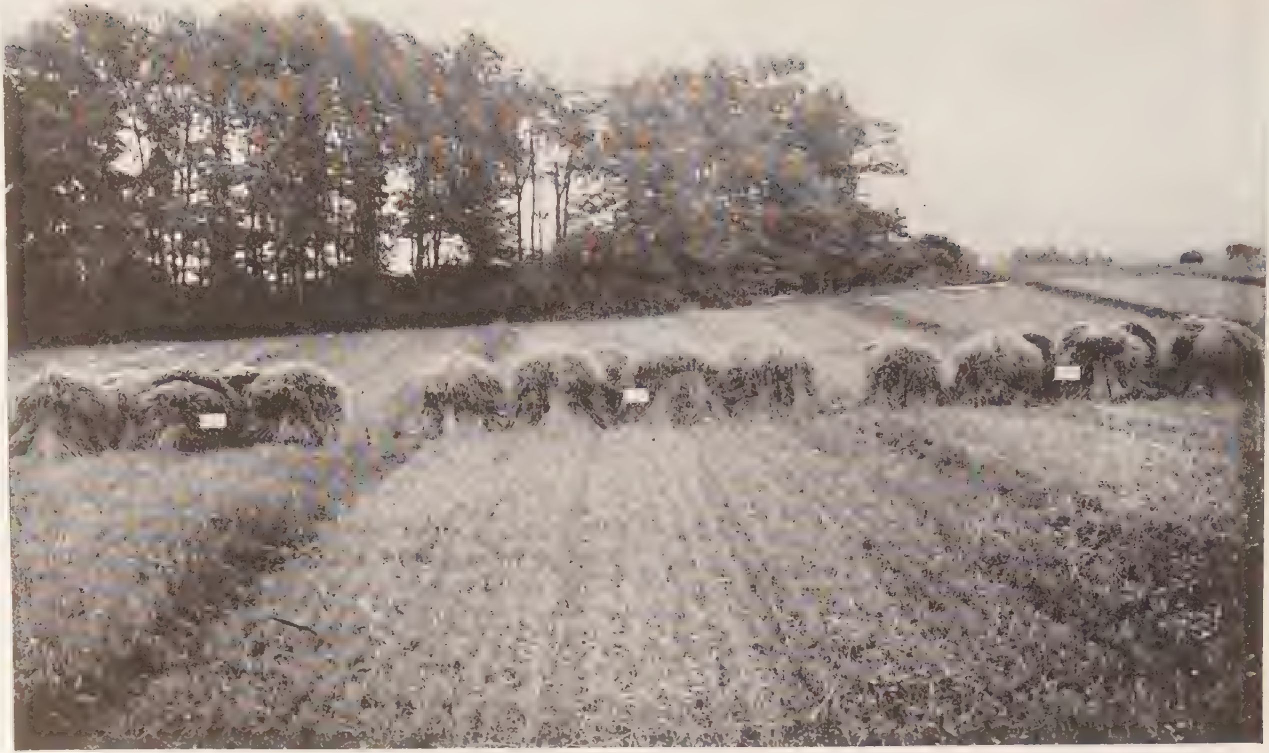

FIGURE XVII.—WHEAT AT PENNSYLVANIA EXPERIMENT STATION

Plot 19 (left) complete fertilizer containing 48 pounds nitrogen. Plot 20 (middle) barnyard manure 10 tons; Plot 21 (right) complete fertilizer containing 72 pounds nitrogen. Courtesy of R. L. Watts, Director, and F. D. Gardner, Agronomist.

TABLE XL.—COMPARATIVE YIELDS OF CORN, OATS AND WHEAT GROWN CONTINUOUSLY AND IN ROTATION FOR THIRTY-FIVE YEARS

CROPPING	*Treatment per acre*			*Yield per acre*	
	Super-phosphate	*Muriate potash*	*Nitrate soda*	*Unlimed land*	*Limed land*
	Lb.	*Lb.*	*Lb.*	*Bu.*	*Bu.*
Corn, continuous	160	100	160	37.81	38.60
Corn, continuous	160	100	320	42.61	44.59
Corn, rotative	80	80	none	38.74	49.33
Oats, continuous	160	100	160	40.65	....
Oats, continuous	160	100	320	48.34	....
Oats, rotative	80	80	none	48.03	....
Wheat, continuous	160	100	160	....	18.98
Wheat, continuous	160	100	320	....	22.28
Wheat, rotative	160	100	none	....	23.66

rotation, on the unlimed land the rotated corn has given larger yields than that grown continuously with the help of 160 pounds of nitrate of soda, and on the limed land larger than that grown continuously with 320 pounds of the nitrate.

The oats can only be compared on unlimed land, but rotation has added nearly as much to the yield as has 320 pounds of nitrate of soda to the continuously grown crop.

The wheat has all been limed in the continuous cropping, and again rotation has given a larger yield than has been harvested in continuous cropping with the help of 320 pounds of nitrate of soda.

At 3½ cents a pound 320 pounds of nitrate of soda will cost $11.20, and nitrate of soda is at once the most effective, and heretofore has been the cheapest commercial carrier of nitrogen. Rotation alone, therefore, has added nearly or quite twice the annual rental value of the land to the value of the crop.

Continuous, versus rotative cropping in farm practice.—On other parts of the land in these Ohio experiments farm manure has been substituted for chemical fertilizers, the manure being applied to every crop in the continuous cropping at the rate of five tons per acre, and to the corn and wheat in the rotative cropping at the rate of eight tons per acre for each crop, thus making the total dressing per

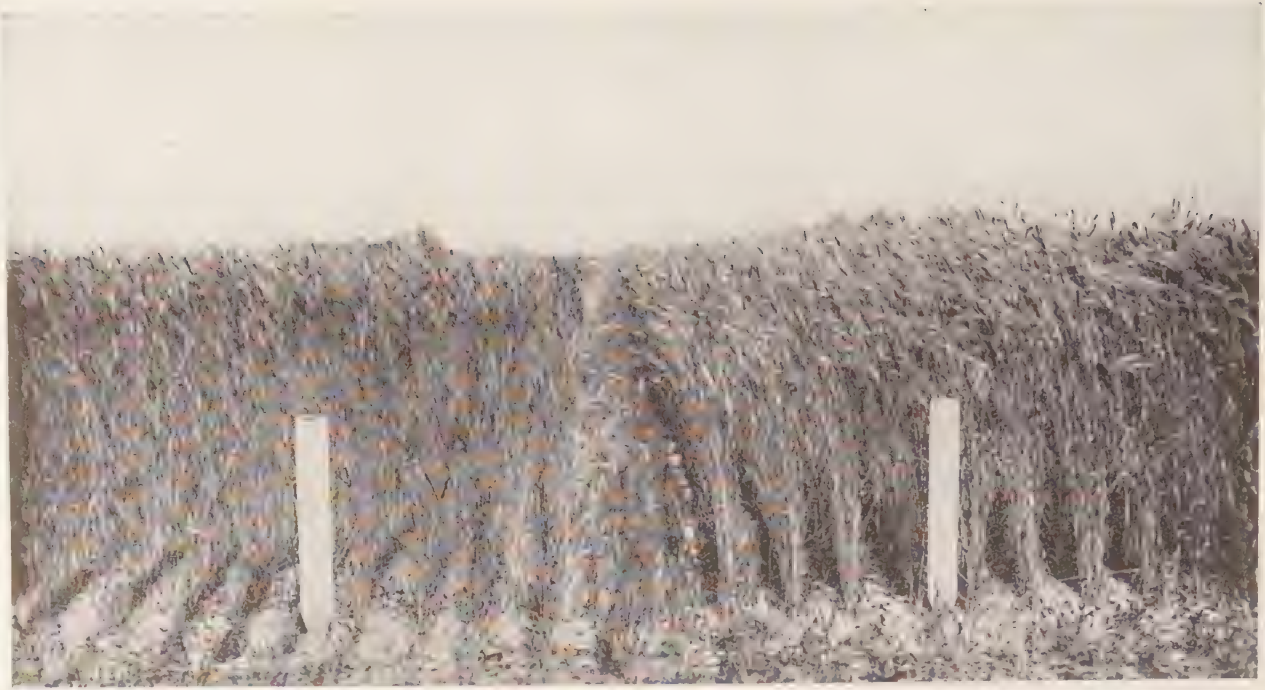

FIGURE XVIII.—WHEAT AT OHIO EXPERIMENT STATION, 5-YEAR ROTATION

Wheat in 5-year rotation on limed land, 1914. Plot 16 (left) unfertilized, 18.7 bushels per acre; Plot 17 (right) nitrogen, phosphorus, and potassium, [illegible] bushels. [illegible] years average yield, Plot 16, 11.7 bushels; Plot 17, 26.5 bushels. Cost of fertilizer for the wheat $6.20, but there has been an average total increase of a ton and a third of hay per acre in the hay crops which have followed the wheat without further fertilizing. Photo by E. J. Houser.

acre for each 5-year period 25 tons in the continuous and 16 tons in the rotative cropping.

At the Missouri Experiment Station corn, oats and wheat have likewise been grown continuously and in rotation since 1889, on both unmanured and manured land, the rotative cropping consisting of a 6-year rotation of corn, oats, wheat, clover, timothy, timothy; a 4-year rotation of corn, oats, wheat, clover; a 3-year rotation of corn, wheat, clover, and a 2-year rotation of wheat and clover. In these rotations only a single plot has been given to each test, so that in order to obtain a representative crop for every season it is necessary to combine all the rotations on the manured land, and to fill in a few gaps on the unmanured land with yields found in the continuous cropping. This has been done in Table XLI, in which the results for the Missouri test are compiled from Bulletin 182 of that Station.

In this test manure, when used, has been applied at an average rate of 6.3 tons per acre on every crop, whether grown continuously or in rotation, hence the total quantity used, especially in the rotative cropping, has been much greater than in the Ohio test.

The results in Table XLI are shown in three successive 10-year periods in both tests, those for the Ohio test being for the limed land for the last two periods.

Table XLI shows that, during the first 10 years there was comparatively little difference in yield of corn between the continuously grown and rotated crops in either test, except on the unmanured land in Ohio, and that the same was true of the wheat in Ohio on both unmanured and manured land, the continuously grown wheat slightly outyielding the rotated wheat; but that from that time forward the rotated crops gave much larger yields than those grown continuously.

The yields of the rotated corn were lower during the third period than during the second, especially in the Missouri test, while those of wheat were all higher excepting the continuously grown wheat in Missouri on unmanured land, an outcome probably due to seasonal conditions. These differences, however, do not affect the general proposition that, under similar treatment in other respects, rotation will eventually give much larger yields than continuous cropping.

Table XLI strikingly illustrates the danger that lies in basing conclusions or establishing a farm practice on the results of a few seasons' observation.

TABLE XLI.—COMPARISON OF CONTINUOUS WITH ROTATIVE CROPPING ON UNMANURED AND MANURED LAND BY TEN-YEAR PERIODS

TREATMENT, STATION AND CROPPING	*Annual yield per acre* *Period I*	 *Period II*	 *Period III*
	Bu.	*Bu.*	*Bu.*
Corn: none, Ohio, continuous	21.5	7.8	6.9
Corn: none, Ohio, rotative	31.3	21.8	18.8
Corn: none, Missouri, continuous	28.4	17.2	16.6
Corn: none, Missouri, rotative	29.1	38.8	26.3
Corn: manured, Ohio, continuous	41.6	28.5	22.9
Corn: manured, Ohio, rotative	45.1	55.1	52.9
Corn: manured, Missouri, continuous	43.1	32.9	25.0
Corn: manured, Missouri, rotative	44.2	55.6	35.3
Wheat: none, Ohio, continuous	9.2	5.8	6.7
Wheat: none, Ohio, rotative	8.9	13.5	15.0
Wheat: none, Missouri, continuous	9.6	11.1	7.7
Wheat: none, Missouri, rotative	16.3	13.9	15.2
Wheat: manured, Ohio, continuous	17.1	18.1	21.4
Wheat: manured, Ohio, rotative	15.8	27.1	27.5
Wheat: manured, Missouri, continuous	18.5	15.4	17.8
Wheat: manured, Missouri, rotative	25.4	22.7	26.0

CONCLUSIONS

Long continued experiments in continuous as compared with rotative cropping, made in England, Ohio, Illinois and Missouri, agree in showing that, while for a few years there may be but little difference in the yields obtained from similar treatments under the two methods, the time eventually arrives when crops grown in systematic rotation with clover give very much greater yields than those grown continuously, except where available nitrogen is added to the continuously grown crops in such quantity as to make its cost prohibitive in the case of the ordinary cereal crops.

XVII

Nitrogen Purveying Crops

The Clovers—Of the various leguminous plants that may be used as nitrogen purveyors the common or medium red clover is especially valuable, because of the wide range of soil and climatic conditions to which it is adapted; of the ease with which it is grown; of its deep-rooting habit, and of the fact that it occupies the land throughout the season if its hay and seed crops are taken.

Mammoth or English, and Alsike or Swedish clovers are less valuable, because their seeds are matured in the hay crop, after which there is no further growth, but these clovers may be grown for a time on soils that are becoming too acid for the medium.

Crimson clover is grown to a considerable extent in some of the southeastern states, but it seldom endures the winter in Ohio, and moreover, it is a comparatively shallow feeder, being practically an annual plant.

Alfalfa, being a perennial, keeps the land covered for several seasons, but is more difficult to start than the clovers, and also is more sensitive to lime deficiency in the soil.

Melilot, or sweet clover, ranks with the Mammoth and Alsike clovers in its habit of seeding, but its quick, rank growth and its deep rooting make it a very desirable plant for some situations. No other crop will so quickly convert a tough, heavy clay into a friable soil as melilot, but it is absolutely useless to attempt to grow it on a lime-deficient soil.

At the Ohio Experiment Station a 3-year rotation of corn, oats and clover was begun in 1905 on land that had been kept in good condition by frequent manuring, the object being to study the effect of various carriers of lime. Since 1922 melilot has been substituted for red clover in this test, with a most remarkable result. Wherever lime has been applied, either as quicklime, hydrated lime or ground limestone, there has been a luxuriant growth of melilot, but it has given a weak and sickly growth or none at all in the absence of lime, however liberal the manuring or fertilizing may have been. And this lime must be in the carbonate or oxide form. On parts of the land gypsum and raw phosphate rock have each been used at the rate of 1,000 pounds per acre on every corn crop, in addition to 8 tons of manure, but the land remains almost as bare of melilot as where no treatment of any sort has been given; yet quicklime and ground limestone have produced almost as large a growth of melilot when used alone as when reinforced with manure or with chemical fertilizers carrying phosphorus and potassium.

The corn and oats have both responded to the manuring and fertilizing as well as to the liming, but for the melilot lime carbonate appears to be the amendment of supreme importance, the outcome indicating that calcium oxide must be converted into carbonate before its full effect is attained.

Some of the wild habits of melilot are suggestive. It seldom invades cultivated fields, but chooses roadsides where the surface soil has been removed, or field entrances where the surface and subsoil have been mixed by trampling of stock or rutting of wagon wheels. The bottom of an old brickyard is a paradise for melilot, or the gullies in old fields in which the subsoil has been exposed by washing. This point has been utilized extensively in Kentucky by seeding such gullies to this plant, its rank growth soon stopping the wash and assisting in filling the gullies. In Iowa the sides of the cuts made in grading the highways are being seeded to melilot for the same purpose, as it grows luxuriantly in such situations, whereas it is often necessary to lime the rich, black surface soil of the same hills before it will grow.

Some animals eat melilot readily as pasture or hay, provided the hay is made before the stems become hard, while others require some time to become accustomed to it, as some people do to codfish or oysters.

The beans—Several members of the bean group of plants have been used for this purpose. In England the large horse bean is quite extensively grown, often being sown in the fall with oats, which is grown as a winter crop in the mild climate of southern England, the stiff, upright bean assisting in preventing the oats from lodging. In Agdell Field at Rothamsted beans have proved less effective than clover in the enrichment of the land in nitrogen.

The Cowpea, which is not a pea, but a bean, is largely grown in the southern United States for this purpose. It may be grown as far north as Ohio, but in that latitude the soybean is much the preferable plant.

Wheat after oats or soybeans—The Ohio Experiment Station has conducted experiments on the county experiment farms in Mahoning, Paulding and Miami counties, in which rotations of corn, oats, wheat and clover, and corn, soybeans, wheat and clover have been compared under varying fertilizer treatments over periods of 10 to 12 years. The Mahoning soil is a silt loam over sandstone, similar to that on which the central station is located in Wayne County; the Paulding soil is the heavy, black clay bottom of ancient Lake Maumee; and the Miami soil is the yellow-and-black soil typical of the Miami Valley.

In the Mahoning test the land is limed for each corn crop, using ground limestone, two tons per acre. In all these tests part of the land is left with no other treatment than the liming in Mahoning; a part receives superphosphate (16 percent) used at the equivalent of 125 pounds per acre per annum; a part receives muriate of potash in addition to the superphosphate, equivalent to 10 pounds per acre per annum in Mahoning and to 22 pounds in Paulding and Miami, and another part receives the same dressings of superphosphate and muriate of potash with the addition of the equivalent of 27½ pounds per acre per annum of nitrate of soda in Mahoning and 40 pounds in Paulding and Miami.

The outcome of these experiments, as indicated in the wheat crop, is shown in Table XLII, which gives the average annual yield of wheat on land receiving the combination of superphosphate and muriate of potash, as computed by adding the increase produced by this combination to the unfertilized yield, and also the average annual value of all the crops in the rotation, computed in the same way, this method of computation, to some extent, neutralizing the inequalities of the soil.

TABLE XLII.—COMPARATIVE YIELDS OF WHEAT WHEN GROWN AFTER OATS OR SOYBEANS. YIELDS AND VALUES PER ACRE PER ANNUM

	Wheat		*Annual value of entire rotation*	
STATION	*After oats*	*After soybeans*	*Oats rotation*	*Soybean rotation*
	Bu.	*Bu.*	*Dol.*	*Dol.*
Mahoning	23.78	23.99	28.74	28.36
Miami	28.47	29.07	33.76	35.46
Paulding	28.52	29.48	34.10	33.38

While the yields of wheat appear to have been slightly larger after soybeans than after oats, the differences are very small, and are not supported by the outcome for the entire rotation, except in Miami County.

In computing the annual values of the two rotations oats are rated at 50 cents a bushel and soybeans at $1.50. Different valuations, of course, would alter the result. At these valuations it would seem that soybeans may well be substituted for oats in regions where the climatic conditions are unfavorable to oats.

This problem is being studied in a fourth experiment located on land annexed to the central farm at Wooster in 1915, in which a large number of different rotations have been established on land receiving a uniform basic treatment of limestone, manure and superphosphate. As reported by Director Williams[1] the 11-year average annual yields of wheat per acre in some of these tests have been as shown in Table XLIII.

TABLE XLIII.—WHEAT FOLLOWING DIFFERENT CROPS, ELEVEN-YEAR AVERAGE YIELD PER ACRE

	Bushels
Wheat following soybeans (66 crops)..................	33.33
Wheat following corn (124 crops).....................	34.31
Wheat following oats (33 crops)......................	37.34
Wheat following clover (33 crops)....................	39.11
Wheat following potatoes (62 crops)......	39.65

These comparisons have been made on land that has been limed and has had the equivalent of 2 tons of manure and 200 pounds of 16 percent superphosphate per acre per annum. Such treatment, which is in line with the best farm practice, would so increase the nitrogen supply that the effect of any further increments of nitrogen would be likely to be less marked than when only the mineral elements of fertility have been furnished, as in the comparisons shown in Table XLII.

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[1] Ohio Ag. Exp. Sta. Bul. 402, p. 28.

Removal of nitrogen by crops grown in rotation—The results shown in Table XLIII are in harmony with the common experience that wheat gives larger yields after potatoes or clover than after oats, and larger after oats than after corn, provided the seedbed is prepared as promptly as possible after the oats crop is harvested, but the reasons for this behavior have not been fully understood. Light is thrown on this problem by Table XLIV, which gives, for 12 of the experiments listed in Table XIX, the quantity of nitrogen removed by the different crops in the rotation from land which has had a basic dressing of superphosphate and muriate of potash only, or these with the addition of limestone in the Mahoning and Wooster tests, the nitrogen removal being computed on average analysis.

Table XLIV shows that corn has been the largest consumer of nitrogen, averaging practically the same removal as clover, but, while clover sometimes seems to leave more nitrogen in the soil than can be accounted for in its roots and stubble (see Chapter XVIII) the quantity left by corn must be measured by that in its stubble and roots alone, which constitute a much smaller proportionate residue than that from clover.[2] This fact, together with the fact that corn continues its growth up to the time for sowing wheat would seem fully to explain the relatively inferior yield of wheat which usually follows when it is sown on corn stubble. Another factor, however, is that such wheat is usually sown a little later than that following oats.

The table shows that the oats crops have consumed much less nitrogen than the corn crops grown in the same rotations, thus leaving a larger reserve for the wheat to draw

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[2] About 30 percent of the total nitrogen of the corn plant, excluding the roots and stubble, is found in the stover; if this is left on the ground the removal will be diminished. In the computation for clover no account is taken of the aftermath, which, when not harvested for seed is pastured or plowed under. These practices would alter the comparison here made.

TABLE XLIV.—REMOVAL OF NITROGEN BY CROPS GROWN IN ROTATION

Test No.	Station	Rotation [3]	Nitrogen removed: Pounds per acre per annum						
			Corn	*Potatoes*	*Oats*	*Soys*	*Wheat*	*Clover*	*Average*
14	Mahoning	C-O-W-Cl	70	..	49	..	40	70	57
15	Mahoning	C-S-W-Cl	68	..	..	79	41	67	64
23	Miami	C-O-W-Cl	93	..	52	..	48	71	66
24	Miami	C-S-W-Cl	97	..	..	86	49	79	78
20	Paulding	C-O-W-Cl	80	..	55	..	48	95	70
21	Paulding	C-S-W-Cl	80	..	..	75	50	95	75
29	Hamilton	C-S-W-Cl	82	..	..	69	35	71	64
56	Hamilton	P-W-Cl	..	23	..	..	62	84	56
30	Clermont	C-S-W-Cl	60	..	..	55	23	35	43
57	Clermont	P-W-Cl	..	20	..	..	47	50	39
5	Wooster	C-O-W-Cl	100	..	54	..	60	105	80
55	Wooster	P-W-Cl	..	45	..	..	67	98	70

[3] C—corn; O—oats; W—wheat; S—soybeans; P—potatoes; Cl—clover.

upon, as well as giving a longer period for this reserve to be made available before the wheat is sown.

Soybeans carry away from the land about as much nitrogen as corn, and like corn are growing up to the time for wheat seeding, thus consuming the nitrogen reserves and sometimes delaying the seeding of the wheat. In root growth soybeans resemble oats or corn, rather than clover, and it appears that the beans have not left any such accumulation of nitrogen in the soil as that left by clover.

The English field bean as a substitute for clover—On Agdell Field, at Rothamsted, the English field bean has been used as a substitute for clover, when clover has failed, but the outcome has been that the yields of wheat following beans have been much smaller than those following clover. In this experiment, however, the beans have been pulled, thus removing a part of the root,[4] but there seems to be no doubt that the annual legumes are much less effective accumulators of soil nitrogen than the biennial clovers.

Table XLIV shows, however, that in the harvested portion of the crop the soybeans have ranked very close to clover as carriers of nitrogen, the average nitrogen content, where both crops have been grown, being the same for the soybeans as for the clover, and that for the entire rotation being in every case greater for the rotations containing soybeans than for those containing oats instead. Regarded from the standpoint of feeding values, therefore, the soybean is a more important crop than when considered merely as a precursor of wheat.

The nitrogen withdrawn by potatoes is computed in Table XLIV for the tubers only, as the tops are usually left on the ground. When thus computed, potatoes are shown to have carried away from the land a far smaller proportion of nitrogen than any other crop in the series, which, taken in connection with the fact that the growth of the potato usually ends some weeks before the wheat is sown, is an adequate explanation of the superior yield of wheat when following potatoes.

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[4] Rothamsted experiments, A. D. Hall, 1905, p. 201.

CONCLUSIONS

That clover should surpass all other crops as a preparation for wheat depends chiefly upon the two facts, that it adds to instead of depleting the nitrogen store in the soil, and that its root growth is of such a character as to leave the land in better physical condition than is done by any other crop.

While a crop of soybeans may contain as much nitrogen as a crop of clover, a larger proportion of the total nitrogen of the crop is removed from the land in the soybeans than in the clover, and thus, whereas the soybean may equal clover as a source of protein in stock feeding, or to be turned under as a green manure, its roots and stubble are inferior to those of clover as purveyors of nitrogen to succeeding crops.

XVIII

How Much Nitrogen Will Clover Furnish?

It is evident, from the results of the experiments described in the preceding chapters, that if crop yields are to be permanently maintained at a profitable level on average soils the lime, phosphorus, potassium and nitrogen removed from the land in the crops must all in some manner be restored.

Farm manure is an efficient carrier of these elements, when properly handled, but it is not practicable to convert all the produce of the land into manure, because a considerable part must be devoted to human necessities, while that part which is fed to livestock suffers unavoidable losses of nitrogen, which must in some manner be recovered. Such losses may be compensated by the purchase of nitrogenous feeding stuffs, and it is good husbandry to follow this practice, although it simply means the depletion of some other soil of its nitrogen, but there are many farmers who are not favorably situated for the handling of livestock, or who lack either the capital, or the skill and adaptation, essential to successful livestock management.

While the cost of the mineral elements necessary to replace the draft upon the soil is not so great but that it may be partially or wholly offset against the labor and other overhead costs involved in the keeping of livestock, the cost of replacing all of the nitrogen, through the purchase of nitrogenous fertilizers, is prohibitive in the production of ordinary farm crops, at the present relative prices of such crops on the one hand and of nitrogenous fertilizers on the other. It therefore becomes important to learn to what extent clover and other leguminous plants may be relied upon to furnish nitrogen to the cereal crops.

The common or medium red clover is the crop most generally grown for this purpose, and the experiments described in the previous chapter have shown it to be the most effective of the crops ordinarily grown. The great value of the hay of this clover as a feeding stuff is one of the prime factors leading to its culture by the live-stock farmer, while the increased production of the crops immediately following clover has led the observing grain farmer to grow it primarily for this purpose, and even to question whether this function of clover may not justify growing it for this purpose alone, and turning under the entire crop as a fertilizer. This problem will be considered in Chapter XXIV.

Reasons for the beneficient effect of clover—Scientific inquiry into the composition of crops and the factors controlling their growth has taught us that this beneficient influence of clover upon other crops may be due in part to each of the following factors:

1. To the mechanical action of the mass of clover roots upon the soil, which they penetrate in every direction, producing that friable texture so readily penetrated by the plant root. This action is performed also by the grasses, but what farmer who has ever followed the plow has not noticed the looser texture of the clover sod than of that of timothy or blue grass?
2. To the more favorable opportunity which this better mechanical condition offers for the action of soil organisms in disintegrating and thus making more available the mineral elements of the soil.
3. To the bringing up of plant nutrients from lower depths in the soil than are reached by other crops and leaving them nearer the surface.
4. To an increase in the available nitrogen content of the soil, not only by the nitrogen stored in the root nodules, but by an increased activity of the nitrifying and nitrogen collecting organisms in the soil, due to the better mechanical condition produced by the clover roots.

Relative proportions of nitrogen in hay and roots of clover—Chemical analyses of different parts of the plant made by several experiment stations and summarized by the late Dr. C. G. Hopkins[1] indicate that about one-third of the nitrogen contained in the red clover plant is found in the roots and stubble. Whether the nitrogen thus stored measures the full effect of clover as a purveyor of nitrogen to other crops can only be determined by rigorous and long continued field experiment, for the problem is complicated by the fact that the original store of nitrogen in the soil may be drawn upon for a considerable period before material exhaustion becomes evident.

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[1] "Soil Fertility and Permanent Agriculture," p. 218.

Effect of clover on crops following in rotation—At the Ohio Experiment Station corn, oats and wheat have been grown separately and in rotation with clover for 35 years, each crop being grown every year in all tests. The outcome of some of this work is shown in Table XLVI, which gives the results for land that has had no manuring or fertilizing throughout the entire period of the test except that it has been limed at intervals since the first 10 years. In these experiments the continuously grown crops have no other source of nitrogen than the natural store in the soil and that brought down in the rainfall, hence the difference between the nitrogen found in these crops and that found in the same crops grown in rotation may be taken as a measure of the effect of the clover, the rainfall having the same effect upon both rotated and continuously grown crops.

Table XLVI.—Effect of Clover Upon Crops Following in Rotation on Unfertilized Land as Measured by Nitrogen Content

	Nitrogen in produce per acre per annum		
	10 years 1894-1903	*15 years 1904-1918*	*10 years 1919-1928*
	Lb.	*Lb.*	*Lb.*
In rotated crops other than clover....	30.4	30.7	31.2
In crops grown continuously.........	23.0	17.9	14.0
Excess in rotated crops..............	7.4	12.8	17.2
In clover hay......................	43.5	38.0	45.2
In excess for 1 pound in hay........	.17	.34	.38

During the earlier years the supply of organic nitrogen in the soil was sufficient to furnish a relatively large proportion of the nitrogen required by both rotated and continuously grown crops—the wheat actually giving a slightly larger yield in the continuous than in the rotative cropping—but with the progress of the seasons this supply was more

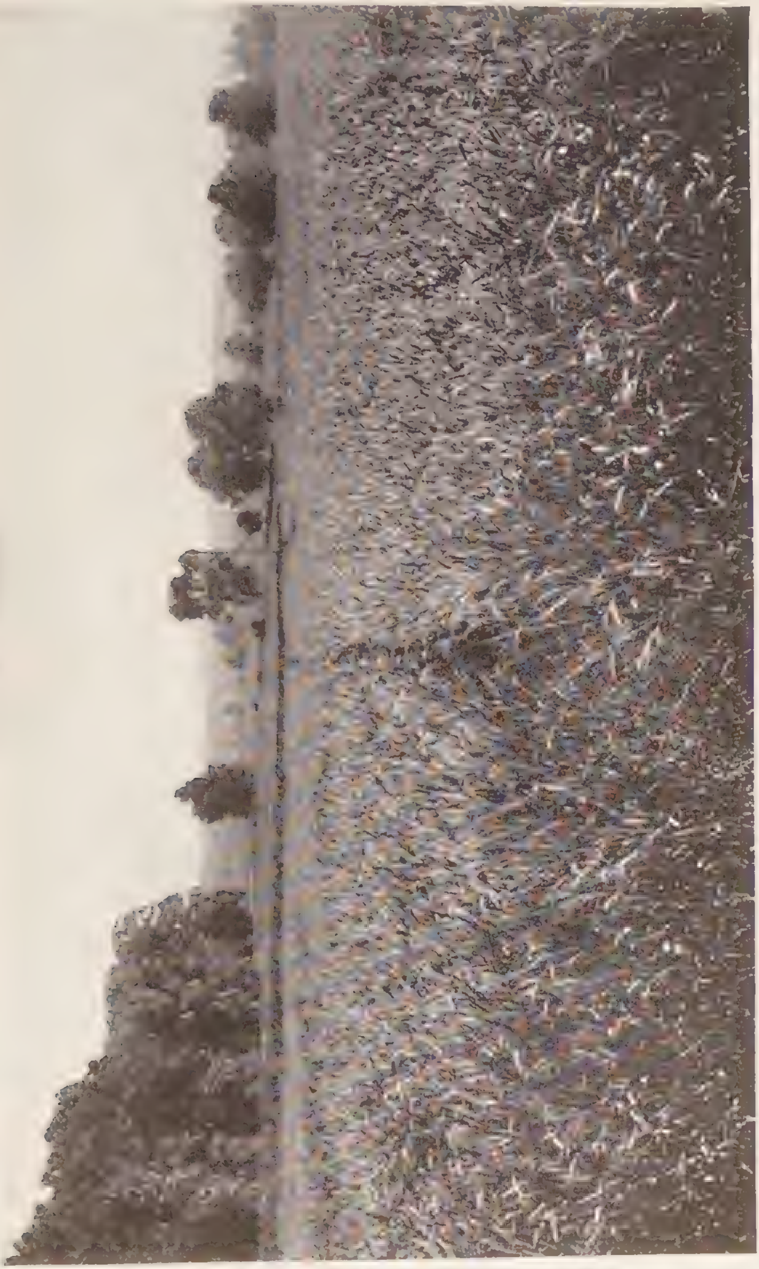

FIGURE XIX.—WHEAT AT OHIO EXPERIMENT STATION, POTATOES-WHEAT-CLOVER ROTATION

Plot 11, left, complete fertilizer; Plot 10, right, unfertilized. 34 years average yield per acre: Plot 11, 38.6 bushels; Plot 10, 27.7 bushels.

and more depleted and that furnished by clover became more important.

In this test, however, the growth of the crops was restricted by the lack of available lime, phosphorus and potassium, without which the nitrogen provided by the clover could not be fully utilized. In Table XLVII is shown the outcome in the rotative cropping when these elements were supplied, the table showing the nitrogen in the increase over the unfertilized yield due to fertilizers carrying these elements.

TABLE XLVII.—NITROGEN IN THE INCREASE OF CROP ON UNLIMED AND LIMED LAND, DUE TO FERTILIZERS CARRYING PHOSPHORUS AND POTASSIUM ONLY

	Nitrogen in increase per acre per annum		
	10 years 1894-1903 Lb.	*15 years 1904-1918 Lb.*	*10 years 1919-1928 Lb.*
	Unlimed land		
In total clover hay	49.0	47.7	30.3
In increase of other crops	42.3	63.1	65.8
In increase for 1 pound in hay	.86	1.32	2.17
	Limed land		
In total clover hay	...	65.1	72.9
In increase of other crops	...	66.8	85.7
In increase for 1 pound in hay	...	1.03	1.17

To understand the meaning of Tables XLVI and XLVII we must remember that, if fertilizers carrying nitrogen only are materially to increase the yield, this nitrogen must find an available store of the mineral elements, and conversely that, if the mineral elements are to have their full effect they must be reinforced with available nitrogen.

Relative effect of nitrogen and mineral elements in Broadbalk Field—Thus, in Broadbalk Field, at Rothamsted, the addition of a large supply of the mineral elements, used alone, has increased the 74-year average yield of wheat by less than two bushels per acre, or about the quantity that would be accounted for by the combined nitrogen brought down in the annual rainfall, while a liberal dressing of nitrogen, given alone in sulphate of ammonia, has added but seven bushels to the annual yield, whereas the combination of the two dressings has increased the yield by nearly 19 bushels.

Yields from minerals only in Ohio rotations—Tables XLVI and XLVII show that, when the mineral elements have been supplied, the effect of the clover upon the other crops has been from three to five times as great as when the land has been left untreated. They also show that this effect increases with the progress of the years; that is, as the original store of nitrogen is depleted the clover supplies the deficiency in increasing measure, and Table XLVIII shows that, on the limed land, not only is this deficiency being made good, but an increasing yield of crops is being supported; thus showing that the soil is not being depleted.

TABLE XLVIII.—SHOWING INCREASING YIELD OF CROPS WHEN GROWN IN ROTATION WITH CLOVER ON LIMED LAND RECEIVING MINERAL FERTILIZERS ONLY

	Annual yield per acre		
	10 years *1894-1903*	*15 years* *1904-1918*	*10 years* *1919-1928*
Corn, Bu.	42.30	48.11	56.81
Oats, Bu.	39.50	50.72	52.05
Wheat, Bu.	17.49	25.33	27.31
Clover, Cwt.	22.78	30.03	33.66
Timothy, Cwt.	27.95	37.84	38.67

Nitrogen in clover hay compared with that in increase of other crops—The experiments upon which Table XLVII is based have been conducted on land that had been depleted of its fertility by a long period of exhaustive cropping before the test was begun, and their outcome raises the two questions, whether similar results may be expected on ordinary soils, and whether a further increase in yield of crops grown in rotation with clover may be obtained by the addition of nitrogenous fertilizers. These questions are answered in part by Table XLIX which gives the outcome of the widely scattered Ohio tests and the Pennsylvania test, the results shown in Table XLVII being repeated for convenient comparison.

Table XLIX shows that, during the first 10 to 16 years of treatment with the mineral fertilizers, the quantity of nitrogen carried in the clover hay has exceeded that in the increase of the other crops of the rotation in every case, excepting only the tests in Washington and Clermont counties (numbers 17 and 30) in which the soybean has taken the place of oats in the rotation. In these two exceptional cases the yields of clover have been lower than in any other test during the same period. In the rotations in which oats and soybeans are compared (numbers 14 and 15, and 23 and 24) the yield of clover has been lower after soybeans than after oats in the Mahoning test and higher in the Miami test; there does not appear, therefore, to be any consistent evidence that the soybeans have had any effect upon the clover, and it seems that when clover yields are abundant the soybean contributes but little to the nitrogen supply, although it may help to bridge over the deficiency caused by clover failure.

Throughout all these tests the second period shows a larger relative increase in the other crops per pound of nitrogen in the clover hay than during the first. In tests numbered 6 and 19 this outcome is evidently due to decreasing yields of clover, and thus indicates soil depletion, but on limed land, in numbers 2 and 9, the yields of all the crops are increasing, as shown by the nitrogen column, while over the limestones, in numbers 28 and 32, although there has been some falling off in the yield of clover, the average yield of the other crops, as measured by total nitrogen content, has been maintained at Germantown and has suffered a comparatively slight reduction in the Pennsylvania test. In both these tests, however, corn, which is a larger consumer of nitrogen and is more sensitive to lack of lime than either oats or wheat, has shown a reduction in yield, indicating that the time has come when both these soils must be limed if maximum yields are to be maintained.

In the 35-year test at Wooster there has been a large reduction in the yield of clover on the unlimed land during the third period. The yields of the other crops are also reduced, but the falling off is greater for the clover than for the other crops, hence the apparent increase per pound of nitrogen in the clover is very large, thus indicating that the soil is being depleted. On the limed land, however, all the crops, including clover, show increasing yields.

It will be observed that the quantity of nitrogen in the increase of other crops in the rotation, as compared with that in the clover hay, is relatively large in the longer rotations

TABLE XLIX.—CLOVER AS A PURVEYOR OF NITROGEN TO CROPS RECEIVING MINERAL FERTILIZERS ONLY, AND FURTHER INCREASE FROM ADDITION OF NITRATE OF SODA

REFERENCE NO.[2]	*Station*	*Rotation*	*Period*		*Nitrogen*			*Nitrate of soda added Lb.*[3]	*Increase per 100 lb. nitrate Dol.*	*Reference No.*
			No.	*Yrs.*	*In clover hay* [3]	*In increase of other crop*				
						Total Lb.[3]	*Per lb. in hay Lb.*			
					Over sandstones and shales					
1	Wooster	Corn, oats, wheat, clover, timothy	I	10	49.0	42.3	.86	96	4.56	1
2a	Wooster	Corn, oats, wheat, clover, timothy	II	15	47.7	63.1	1.32	96	5.09	2a
2b	Wooster	Corn, oats, wheat, clover, timothy; L	II	15	65.1	66.8	1.03	96	3.51	2b
2c	Wooster	Corn, oats, wheat, clover, timothy	III	10	30.3	65.8	2.17	96	5.61	2c
2d	Wooster	Corn, oats, wheat, clover, timothy; L	III	10	72.9	85.7	1.17	96	2.55	2d
5	Wooster	Corn, oats, wheat, clover; L		14	105.0	44.4	.42	27	9.50	5
6a	Wooster	Corn, oats, clover	I	12	57.4	34.3	.60	..	...	6a
6b	Wooster	Corn, oats, clover	II	11	33.0	34.5	1.05	..	...	6b
8	Strongsville	Corn, oats, wheat, clover, timothy	I	10	44.4	37.7	.85	96	2.14	8
9	Strongsville	Corn, oats, wheat, clover, timothy; L	II	16	59.3	54.7	.92	96	2.00	9
13	Trumbull Co.	Corn, oats, wheat, clover; L		10	64.9	35.4	.54	27	2.70	13
14	Mahoning Co.	Corn, oats, wheat, clover; L		10	77.6	40.1	.52	27	6.55	14
15	Mahoning Co.	Corn, soys, wheat, clover; L		10	66.3	63.1	.95	27	2.10	15
16	Belmont Co.	Corn, corn, wheat, clover		10	53.2	17.9	.34	30	6.70	16
17	Washington Co.	Corn, soys, wheat, clover		12	28.3	46.6	1.65	40	4.10	17
19a	Carpenter	Corn, wheat, clover	I	12	43.1	25.5	.59	53	5.60	19a
19b	Carpenter	Corn, wheat, clover	II	12	21.7	32.9	1.50	53	5.57	19b
					Over limestones					
20	Paulding Co.	Corn, oats, wheat, clover		15	93.4	...	...	40	6.52	20
21	Paulding Co.	Corn, soys, wheat, clover		14	95.9	16.1	.17	40	3.32	21
22	Hancock Co.	Corn, oats, wheat, clover		13	55.0	27.6	.50	40	—1.70	22
23	Miami Co.	Corn, oats, wheat, clover		16	69.5	61.5	.88	40	—1.67	23
24	Miami Co.	Corn, soys, wheat, clover		16	81.6	72.9	.89	40	—.86	24
25	Miami Co.	Corn, corn, oats, clover		16	71.6	51.1	.71	40	—2.17	25
26	Miami Co.	Corn, wheat, clover		12	58.6	44.9	.77	43	.14	26
27	Madison Co.	Corn, corn, wheat, clover		8	79.3	41.1	.52	15	.80	27
28a	Germantown	Corn, wheat, clover	I	12	67.6	29.7	.44	53	2.98	28a
28b	Germantown	Corn, wheat, clover	II	12	52.7	39.0	.72	53	1.64	28b
29	Hamilton Co.	Corn, soys, wheat, clover		14	70.4	57.1	.81	40	2.02	29
30	Clermont Co.	Corn, soys, wheat, clover		13	35.1	67.5	1.92	40	7.05	30
31	Pennsylvania	Corn, oats, wheat, clover	I	25	89.6	38.5	.43	150	1.03	31
32	Pennsylvania	Corn, oats, wheat, clover	II	15	81.1	66.9	.82	150	1.74	32

[2] The numbers correspond to those in Table XIX. [3] Per acre per annum. L—limed land.

at Wooster and Strongsville, in which clover is grown but once in five years, but a comparison of the yields in these tests by periods shows that they are increasing in both tests, hence the soil cannot be suffering any serious depletion.

Further increase from nitrate of soda in crops rotated with clover—Turning to the second part of Table XLIX, it appears that nitrate of soda, when used at rates equivalent to 96 pounds per acre per annum, has paid its cost, if that be reckoned at $3.50 per hundred pounds, only on the unlimed land at Wooster. When used at the smaller rates, of 27 to 53 pounds, its cost has been recovered with profit over the sandstones, except in the Trumbull county test and in the soybean rotation in Mahoning county; but over the limestones the cost of the nitrate has been recovered only on the Paulding and Clermont soils, while on the Miami county soil it has apparently actually reduced the yield, except in the 3-year rotation.

The soils of the Strongsville and Trumbull county experiment farms more nearly represent the Volusia type than any other Ohio soil under experiment, and these soils agree with the Miami soil in their indifference toward nitrogen fertilizing, although they disagree in their response to potassic fertilizers. The soils that are responding to nitrogenous fertilizers are the Wooster and nearly related Canfield soils of the Wooster and Mahoning county experiment farms; the non-glaciated sandstone soils formerly classed in the Dekalb series, now separated under the name Muskingum, found on the Belmont county, Washington county and Meigs county (Carpenter) experiment farms, all in southeastern Ohio; the Clermont soil on the old Illinoian glaciation, and, singularly, the Paulding soil, where it would seem that the crude organic nitrogen of this former marsh land is so slowly available that the land is ready to make use of the quickly available nitrate. Moreover, this Paulding soil is so highly stocked with phosphorus, potassium and lime that the addition of these substances meets only a negative response, actually diminishing the yield in some cases.

On the limestone soil of the Pennsylvania test nitrogen has been used in such large quantity that its effect is obscured, but the increase of crops produced in excess of that due to the mineral fertilizers has been so small that it seems doubtful whether any smaller dose would have shown a profit.

CONCLUSIONS

In the experiments under consideration corn, oats and wheat have been grown separately and in rotation with clover on several types of soil. When the land has been left untreated except with lime the increase in yield of the rotated crops over those grown separately has accounted for considerably less than half as much nitrogen as that found in the clover hay of the rotated crops.

When fertilizers carrying phosphorus and potassium have been added to the treatment of the rotated crops the yields of all the crops have been materially increased, the average increase in the grain crops due to this treatment accounting for more than half as much nitrogen as that found in the larger yields of clover hay for periods of 10 to 16 years on both limed and unlimed land.

When the tests have been continued for longer periods there has been a further increase on limed land in crop yields and in apparent effect of clover, but on unlimed land the clover yields have fallen off more rapidly than those of the other crops, thus indicating that the yields are being maintained at the expense of the soil store of nitrogen, an indication confirmed by the 35-year test at Wooster, in which the grain yields are falling off on the unlimed land.

While in most cases the yields have been further increased by the addition of nitrogen to the mineral fertilizers the value of this increase, at present relative prices of crops and fertilizer nitrogen, has generally been less than the cost of the nitrogen required to produce it, except on unlimed land where the clover yields have become low.

It appears, therefore, that if the supply of available phosphorus and potassium be made ample, and if the land be kept hospitable to clover by liming when necessary, the root growth of clover, grown in rotation with other crops, may be relied upon to furnish to subsequent crops, directly or indirectly, more than half as much nitrogen as that contained in the hay, and that the nitrogen thus supplied will so nearly meet the requirements of two or three crops following the clover that the application of nitrogenous fertilizers will be without effect on many soils and of relatively small effect generally.

XIX

Commercial Carriers of Nitrogen

Nitrate of soda is found in immense natural deposits in a rainless desert in northern Chile, where it is obtained by surface mining, refined, and sold under control of the Chilean government. It is a coarse, hygroscopic salt, usually somewhat lumpy, making it necessary to run it over a sand sieve and pulverize the lumps with a pestle. For small quantities a hand sieve may be made by stapling a square of wire netting with quarter-inch mesh to a bottomless box. Being already in nitrate form and easily soluble it is quickly effective, as may be seen by sowing it on young wheat in April and observing the darkening color of the wheat a day or so after the next shower of rain. Because of its soda base it is the most suitable carrier of nitrogen for acid soils. It should contain 15½ to 16 percent nitrogen.

Sulphate of ammonia is a by-product from the production of coke and gas from coal. It is sold as a finer salt than nitrate of soda and should contain about 21 percent nitrogen. Being in the form of ammonia its nitrogen must be converted into nitrate for most crops, a process requiring the help of the nitrifying bacteria, and as these require lime or an equivalent alkaline base for their functioning the continued use of sulphate of ammonia so exhausts the soil of its lime that the bacteria can no longer work and the added nitrogen fails to serve its purpose. Ammonium salts, therefore, should be used only on land naturally or artificially well supplied with lime. When so used they stand next to nitrate of soda in effectiveness.

Dried blood and tankage were formerly used extensively as carriers of fertilizer nitrogen, but the demand for these materials to be used as sources of protein in stock feeding has practically taken them out of the fertilizer trade.

The various **oilmeals** are useful carriers of nitrogen, but the feeders have pre-empted the first claim to these also.

Since the World War the fixation of atmospheric nitrogen has been made commercially practicable, and **Cyanamid** and other synthetic nitrogen products seem likely to take a leading place as sources of fertilizer nitrogen. There has not yet been enough field work done with these materials fully to determine their relative effectiveness. In a 14-year test at Wooster the effect of Cyanamid has been 87 percent of that of nitrate of soda, in a rotation of corn, oats, wheat and clover. A synthetic nitrogen compound is now available under the name of Arcadian nitrate of soda with the claim that it is free from the lumpiness characteristic of the Chilean nitrate.

Comparison of nitrogen carriers—The soil of the Rothamsted Experimental Station is underlaid with chalk, which was dug up and mixed with the surface more than a century ago, at an estimated rate of more than 100 tons per acre. The Woburn soil lies over the Lower Greensand formation; both are residual soils. Analyses indicate fully six times as much lime in the upper nine inches of the Rothamsted soil as in the same depth of that at Woburn.

In the Rothamsted experiments a mixture of sulphate and chloride of ammonium, carrying 43 pounds of nitrogen annually per acre, has been used for 74 years on continuously grown barley in contrast with nitrate of soda carrying the same quantity of nitrogen. Where the nitrogen carriers have been used alone the average annual yield per acre has been 24.0 bushels from the ammonium salts and 24.5 bushels from the nitrate of soda. When reinforced with superphosphate the yields have been 36.4 bushels from the ammonium salts and 39.3 bushels from the nitrate.

The same carriers, used on wheat for 30 years at the two rates of 43 and 86 pounds of nitrogen per acre annually in connection with superphosphate and sulphates of potash, soda and magnesia, have produced annual yields of 20.1 and 28.3 bushels per acre respectively for the two quantities of ammonium salts and 25.3 and 29.2 bushels for the two quantities of nitrate of soda.

At Woburn wheat and barley have been grown continuously for 50 years, under treatment with sulphate of ammonia and nitrate of soda, each carrying 41 pounds of nitrogen annually per acre for 30 years and half that quantity thereafter, and each used both alone and reinforced with superphosphate and sulphate of potash. The outcome of this test is shown in Table L, which gives by 10-year periods the average unfertilized yields and the increase over these yields due to the different treatments.

Table L shows that for 20 years there was comparatively little difference in the effect of the nitrogen carriers, nitrate of soda being somewhat superior for barley, but at the end of this period with barley and a little later with wheat sulphate of ammonia became actually toxic, reducing the yields below those on the continuously unfertilized land, and completely destroying the crop in some seasons when used alone, and even when used with the minerals, in the case of barley. (See Fig. XX, page 223.)

Table L.—Comparison of Carriers of Nitrogen at Woburn. Average Annual Unfertilized Yields per Acre and Increases From Treatment, by Periods

	Bushels per acre				
	1877-86	*1887-96*	*1897-06*	*1907-16*	*1917-26*
	41 lb. nitrogen			*20½ lb. nitrogen*	
Barley: unfertilized yield	25.0	17.6	12.5	9.2	7.9
Increase					
Sulphate ammonia alone	12.5	10.7	—7.7	—10.0	—7.0
Nitrate soda alone	15.4	13.3	11.2	6.0	3.5
Sulphate ammonia and lime 2 tons 1897, 1912	...	...	8.7	4.3	0.2
Sulphate ammonia and minerals	19.0	17.5	—5.3	—6.4	—3.0
Nitrate soda and minerals	23.0	23.0	21.9	11.2	9.5
Sul. am., minerals and lime 2 tons 1897, 1912	...	...	22.0	11.9	6.1
Wheat: unfertilized yield	17.2	13.6	9.7	9.9	7.1
Increase					
Sulphate ammonia alone	8.6	9.5	0.1	—8.9	—6.1
Nitrate soda alone	6.9	9.6	7.4	7.9	8.2
Sulphate ammonia and lime 2 tons 1897	...	...	7.2	5.8	0.7
Sulphate ammonia and minerals	14.3	15.4	14.7	5.9	2.4
Nitrate soda and minerals	15.0	15.6	12.8	7.1	8.7
Sul. ammonia, minerals and lime 1 ton 1905	...	...	...	11.6	6.1

Nitrate of soda, however, has maintained a fairly uniform increase, as measured in bushels per acre, throughout the 50 years of the test, considering the reduction of application during the last 20 years, and an actually increasing effect, if computed in percentage of the unfertilized yields.

The addition of lime has apparently counteracted the toxic effect of the ammonium salt, and when liming is added to mineral fertilizing, the yields from sulphate of ammonia become equal to those from nitrate of soda, used without the help of lime. The table shows, however, that the liming must be repeated if yields are to be maintained.

At the Pennsylvania Experiment Station corn, oats, wheat and clover have been grown in a 4-year rotation since 1882, each crop being grown every year. In this test sulphate of ammonia and nitrate of soda are used in quantities carrying 12, 24 and 36 pounds of nitrogen per acre per annum, in conjunction with 150 pounds superphosphate and 100 pounds muriate of potash. The results of this test for the forty years, 1882-1921, are shown in Table LI, compiled from Bulletin 175 of that Station. This table gives the excess in average annual value per acre due to the two nitrogen carriers over the values of the crops receiving the superphosphate and muriate of potash only, arranged in five periods of eight years each.

TABLE LI.—COMPARISON OF CARRIERS OF NITROGEN AT PENNSYLVANIA EXPERIMENT STATION. EXCESS OR DECREASE (—) IN ANNUAL VALUE PER ACRE DUE TO SULPHATE AMMONIA OR NITRATE SODA IN THE FERTILIZER

PERIOD	*12 pounds nitrogen*		*24 pounds nitrogen*		*36 pounds nitrogen*	
	Sulphate ammonia	*Nitrate soda*	*Sulphate ammonia*	*Nitrate soda*	*Sulphate ammonia*	*Nitrate soda*
	Dol.	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*
1882-1889	3.23	2.94	5.34	3.30	4.38	3.28
1890-1897	—1.01	.33	.19	.91	—1.61	1.52
1898-1905	—.05	1.22	—.89	2.24	—2.22	2.57
1906-1913	—1.46	2.30	—4.39	3.36	—7.87	3.76
1914-1921	—1.55	3.02	—7.71	3.75	—11.87	4.53

It appears from the table that during the first period sulphate of ammonia produced larger increases in yield than nitrate of soda in each of the three comparisons, but that from that time forward the sulphate reduced, instead of increasing the yield, this toxic effect increasing with the size of the dressing and with the progress of the work. Nitrate of soda, however, has produced a small but consistent increase throughout the 40 years, the effect increasing with the quantity used and with the years.

Dried blood has also been used in parallel treatments in this test, giving increases slightly below those due to nitrate of soda.

The Ohio Experiment Station has used sulphate of ammonia and nitrate of soda in balanced mixtures of these salts with superphosphate and muriate of potash, in a 5-year rotation of corn, oats, wheat, clover and timothy for 35 years at Wooster and 32 years at Strongsville, and in a 3-year rotation of potatoes, wheat and clover for 34 years at Wooster. Since the first 10 years half the land at Wooster and Strongsville has been limed for every corn crop, the other half being left untreated at Wooster and dressed for a few years with raw phosphate rock at Strongsville, and all the land in the potato rotation has been limed.

In the 5-year rotations superphosphate and muriate of potash are used without nitrogen in quantities carrying 10 pounds phosphoric acid and 26 pounds potash per acre per annum, while in the comparisons between the nitrogen carriers the phosphoric acid is increased to 15 pounds, the potash remaining unchanged. It is therefore not possible to calculate the separate effect of nitrogen as accurately as is done in the Pennsylvania test, but, taking the results as they stand, the excess values of the treatments containing nitrogen over those from which nitrogen is omitted are shown in Table LII for three periods of ten years each and a final period of 5 years at Wooster and for two 10-year periods and a final one of 12 years at Strongsville.

The Strongsville test is computed for the four crops, corn, oats, wheat and clover only, the timothy being omitted because of frequent failures of that crop. The table gives the increases over the basic treatments of lime and raw phosphate combined, an analysis of the separate results having shown that, insofar as the effect of the nitrogen carriers is concerned, there has been no material difference in the outcome due to the two basic treatments.

Table LII shows that in both these tests, as in the Pennsylvania test, sulphate of ammonia produced a larger increase than nitrate of soda during the first period, but that thenceforward the return for nitrate of soda exceeded that for sulphate of ammonia in every comparison, both on unlimed and limed land, although the excess was greater on unlimed land.

TABLE LII.—COMPARISON OF CARRIERS OF NITROGEN IN FIVE-YEAR ROTATIONS AT WOOSTER AND STRONGSVILLE. VALUE OF INCREASE FROM MINERALS ALONE AND EXCESS DUE TO THE ADDITION OF SULPHATE OF AMMONIA OR NITRATE OF SODA TO THE FERTILIZER. PER ACRE PER ANNUM BY PERIODS

PERIOD	*Total increase*			*Excess for nitrogen*[1]	
	From minerals alone	*From minerals and nitrogen*			
		In sulphate of ammonia	*In nitrate of soda*	*In sulphate of ammonia*	*In nitrate of soda*
	Dol.	*Dol.*	*Dol.*	*Dol.*	*Dol.*
		Wooster: Unlimed land			
1894-1903	5.82	7.90	7.76	2.08	1.94
1904-1913	8.74	10.20	12.45	1.46	3.71
1914-1923	8.62	10.84	13.71	2.22	5.09
1924-1928	9.44	11.44	15.36	2.00	5.92
		Wooster: Limed land			
1904-1913	9.39	12.32	13.85	2.93	4.46
1914-1923	10.12	12.64	14.20	2.52	4.08
1924-1928	13.48	13.92	15.12	0.44	1.64
	Strongsville: Unlimed first period, limed and raw-phosphate treated since				
1895-1904	6.40	8.18	7.81	1.78	1.41
1905-1914	6.80	7.08	9.28	0.28	2.48
1915-1927	7.39	7.88	9.71	0.49	2.32

The falling off in the increase from nitrogen during the last period on the limed land at Wooster has been coincident with a marked increase, on that land, in the effect of potash, manifested especially in the corn crop. At Strongsville this effect has been less conspicuous, but the superiority of nitrate of soda throughout the later periods has been relatively much greater there than at Wooster.

In the potatoes-wheat-clover rotation the mineral fertilizers are used in the same quantities of 320 pounds superphosphate and 200 pounds muriate of potash per acre for each 3-year rotation, whether with or without nitrogen. The outcome in this test is arranged in Table LIII in three periods, two of 12 years each and a final one of 10 years. During the first period the land was unlimed except for one liming applied before sowing the wheat in 1903, this wheat crop and the clover following on one of the three ranges of plots being the only crops that received any lime during this period. During the next 12 years all the land received one or two limings, but no lime was applied during the final period.

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[1] Nitrogen is applied in these tests at the equivalent of 7½ pounds per acre per annum.

The nitrogen carriers have been used in this test in quantities carrying the equivalent of 8 1-3 pounds of nitrogen per acre per annum, the treatment being equally divided between the wheat and potatoes.

TABLE LIII.—COMPARISON OF CARRIERS OF NITROGEN IN POTATOES-WHEAT-CLOVER ROTATION AT WOOSTER. UNFERTILIZED YIELDS, INCREASE FROM MINERALS ALONE AND EXCESS IN INCREASE DUE TO THE ADDITION OF SULPHATE OF AMMONIA OR NITRATE OF SODA TO THE FERTILIZER. PER ACRE PER ANNUM BY PERIODS

PERIOD	*Crop*	*Unfertilized yield*	*Increase for minerals*	*Excess for nitrogen*	
				In sulphate of ammonia	*In nitrate of soda*
1894-1905	Potatoes, bu. ...	160.59	26.50	1.92	11.02
-	Wheat, bu.	25.33	7.37	2.64	1.76
-	Hay, cwt.	32.51	2.35	—0.40	4.13
-	Value of excess due to nitrogen........			$1.54	$4.50
1906-1917	Potatoes, bu. ...	103.78	45.94	1.63	—1.37
-	Wheat, bu.	26.47	8.19	5.01	5.64
-	Hay, cwt.	34.35	5.47	2.70	4.00
-	Value of excess due to nitrogen........			$3.06	$2.78
1918-1927	Potatoes, bu. ...	81.66	52.12	2.68	—1.30
-	Wheat, bu.	24.12	13.20	3.90	2.78
-	Hay, cwt.	35.80	7.88	2.30	4.45
-	Value of excess due to nitrogen........			$2.80	$1.71

Table LIII shows that before liming was begun the potatoes gave a considerably greater increase from nitrate of soda than from sulphate of ammonia, but that after liming the outcome was reversed. The wheat, following general experience, shows at first a slightly greater increase from the ammonium salt than from the nitrate, which is repeated during the last period. The clover shows a regularly greater increase from the nitrate.

Wheat thrives exceptionally well after potatoes, apparently because the potato crop leaves the land in condition to furnish sufficient nitrogen to support a large crop of wheat without the addition of any nitrogenous fertilizer. In this experiment the actual crop yields as a 34-year average have been as shown for certain treatments in Table LIV.

Table LIV.—Thirty-four Years Average Yields of Potatoes, Wheat and Clover Following Certain Treatments, All per Acre per Annum

	Fertilizers per acre						*Yield per acre*		
	On potatoes			*On wheat*					
Plot No.	*Superphosphate Lb.*	*Muriate potash Lb.*	*Nitrate soda Lb.*	*Superphosphate Lb.*	*Muriate potash Lb.*	*Nitrate soda Lb.*	*Potatoes Bu.*	*Wheat Bu.*	*Clover Lb.*
[2]	...	...	...	...	...	...	117	25.6	3,525
8	160	100	...	160	100	...	157	36.9	4,248
11	160	100	80	160	100	160	156	38.6	4,366
12	160	100	160	160	100	240	163	39.0	4,554
14	320	200	160	160	100	160	170	39.6	4,513

Table LIV shows that the effect of adding nitrogen to the fertilizer in this test has been insignificant, as compared with that of the mineral fertilizers; the clover, with the aid of the minerals and lime, having so nearly met the demand of the other crops for nitrogen as to obscure any differences due to the nitrogen carrier. In no case in this test has the cost of the nitrogen been recovered in the increase due to its use.

Potatoes were grown continuously at Rothamsted for 26 years, with the outcome that mineral fertilizers alone increased the yield by an average of 31 bushels per acre, while the addition of 86 pounds of nitrogen to the minerals gave a further increase of 75 bushels where the nitrogen was carried in sulphate of ammonia and 78 bushels where it was carried in nitrate of soda. This outcome, compared with that of the Ohio test, illustrates the value of clover as a nitrogen purveyor.

Nitrogen on tobacco—A 3-year rotation of tobacco, wheat and clover has been in progress on the Southwestern Test Farm of the Ohio Experiment Station at Germantown since 1904. The soil of this farm is a typical Miami loam, derived from the disintegration of glacial gravels consisting chiefly of limestone. A comparison of sulphate of ammonia and nitrate of soda is in progress in this rotation, nitrogen being applied at the equivalent of 12½ pounds per acre per annum and in connection with the equivalent of 160 pounds of superphosphate and 60 pounds of muriate of potash per annum, but in this test the fertilizers are all applied to the tobacco, the wheat receiving no direct treatment. The average outcome for 24 years is shown in Table LV.

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[2] Unfertilized.

Table LV.—Comparison of Carriers of Nitrogen in Tobacco-Wheat-Clover Rotation at Germantown. Average Annual Increase per Acre From Mineral Fertilizer and Excess Due to Addition of Carriers of Nitrogen; All per Acre per Annum

Crop	Increase for minerals	*Excess for nitrogen*			
		Nitrogen alone		*Nitrogen and lime*	
		In sulphate ammonia	*In nitrate soda*	*In sulphate ammonia*	*In nitrate soda*
		First period			
Tobacco, cwt. ..	6.19	.69	.81	.67	.37
Wheat, bu.	12.33	1.80	2.30	4.67	4.14
Clover, cwt.	16.25	—3.12	—1.09	1.62	1.70
		Second period			
Tobacco, cwt. ..	5.11	.83	.61	.70	.39
Wheat, bu.	18.20	—1.36	—1.68	2.37	3.17
Clover, cwt.	14.90	—2.23	—.73	3.92	3.64

In this test the check plots have not been limed, hence the increases shown on the limed land are due to the combination of lime and nitrogen. Lime has apparently affected tobacco adversely, while it has increased the yields of wheat and clover, converting the losses shown from both nitrogen carriers, especially the ammonium salt, into definite gains.

In this tobacco rotation, as in the potato rotation, the effect of adding nitrogen to the mineral fertilizer has been insignificant, and where lime is added the two nitrogen carriers have had practically the same total effect.

Nitrogen on permanent meadow—An experiment in the fertilizing of permanent meadow has been in progress in the Rothamsted Park since 1856. The soil is the same reddish loam, lying over chalk, as that of Broadbalk and Hoos Fields, but as it has been in grass for centuries the chalk has never been brought to the surface as in those fields. Since 1883 the plots in this experiment have been divided, and half the land has been dressed with lime, 2000 pounds per acre, applied at intervals averaging about seven years.

Some of the results of this work are shown in Table LVI, which gives the average annual yields of hay for the first 10 years of the test and for the seven years, 1920-1926.

The complete minerals on Plot 7 have consisted of 392 pounds superphosphate, 500 pounds sulphate of potash and 100 pounds each of the sulphates of soda and magnesia.

Table LVI shows that the continuously untreated land has ended the 61 years of the test with yields but little lower than those at the beginning. The principal change on this land has been a relative increase in the growth of weeds, which have comprised nearly one-third of the total produce during the last period.

Lime has produced practically no effect in this test when used alone, but it has materially increased the effect of fertilizers containing salts of potassium and ammonium.

The complete mineral fertilizer has a little more than doubled the yield, and has greatly increased the proportion of clover and other leguminous plants in the produce.

Effect of sulphate of ammonia on lime-deficient soils—The combination of the complete minerals with ammonium salts containing 86 pounds of nitrogen, on Plot 9, has added but little to the increase on unlimed land over that due to the minerals alone but has nearly doubled that increase on limed land.

The substitution of nitrate of soda for ammonium salts in this combination has resulted on the unlimed land in 3½ times the gain due to nitrogen given by the ammonium salts, but in a relatively smaller gain on limed land.

On the unlimed land 86 pounds of nitrogen in nitrate of soda has given a larger gain than 129 pounds of nitrogen in ammonium salts, but on the limed land the gain from the ammonium salts has again been relatively greater than that from nitrate of soda.

The clovers have been practically exterminated where ammonium salts are applied, and nearly so after nitrate of soda.

In the earlier years of the Rothamsted work the ammo-

TABLE LVI.—COMPARISON OF CARRIERS OF NITROGEN ON GRASS LAND AT ROTHAMSTED. AVERAGE ANNUAL YIELDS AND INCREASE PER ACRE IN ENGLISH HUNDREDWEIGHTS

PLOT	*Treatment*	*Nitrogen in fertilizer*	*Yield first period*	*7 years, 1920-1926*					
				Yield		*Total increase*		*Gain for nitrogen*	
				Unlimed	*Limed*	*Unlimed*	*Limed*	*Unlimed*	*Limed*
No.		*Lb.*	*Cwt.*	*Cwt.*	*Cwt.*	*Cwt.*	*Cwt.*	*Cwt.*	*Cwt.*
3	None	...	22.6	19.7	20.1	...	...	...	...
4-1	Superphosphate	...	24.4	27.7	24.6	8.0	4.5	...	...
7	Complete minerals	...	33.9	42.9	47.2	23.2	27.1	...	...
9	Minerals and ammonium salts	86	53.6	52.0	67.5	32.3	47.4	9.1	20.3
14	Minerals and nitrate soda ...	86	53.1	75.1	66.5	55.4	46.4	32.2	19.3
11-1	Minerals and ammonium salts	129	61.7	73.1	80.5	53.4	60.4	30.2	33.3
16	Minerals and nitrate soda ...	43	48.1	52.6	51.1	32.9	31.0	9.7	3.9

Botanical composition, 1920-1924

PLOT	*Treatment*	*Gramineae*		*Leguminoseae*		*Other orders*	
		Unlimed	*Limed*	*Unlimed*	*Limed*	*Unlimed*	*Limed*
No.		*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
3	None	59.7	59.1	7.7	9.8	32.6	31.1
7	Complete minerals	59.5	52.0	20.6	37.5	19.8	10.5
9	Minerals and ammonium salts	98.3	97.9	0.1	0.2	1.6	1.8
14	Minerals and nitrate of soda..	95.1	92.8	2.0	2.4	4.7	4.8
19	Farm manure	79.2	80.6	11.1	11.5	9.7	8.0

nium salts were a mixture of the sulphate and chloride, but in later years the sulphate has been used alone.

Throughout this test the evidence is conclusive that, *in the absence of lime,* nitrate of soda is a more effective carrier of nitrogen in fertilizers than sulphate of ammonia.

CONCLUSIONS

These experiments, which have been running for periods of 24 to 74 years in widely separated regions, and have included the principal field crops except cotton, all tell the same story, namely: that on soils kept well supplied with lime sulphate of ammonia appears to be practically equal to nitrate of soda as a carrier of nitrogen in fertilizers, pound for pound of nitrogen contained, but that the continued use of sulphate of ammonia may so exhaust the lime supply as to make it much less effective, and that on soils originally deficient in lime it may eventually become even toxic in effect, whereas nitrate of soda produces increasing yields on such soils.

On Broadbalk and Hoos Fields, which have been heavily chalked, there has not been a great difference in the effect of the two salts; but on the Rothamsted Park, which has been in grass for centuries, nitrate of soda is producing much the larger increase.

On the sandy Woburn soil there was but little difference in the effect of the two salts for 20 years, but since that period sulphate of ammonia has become toxic to wheat and barley on unlimed land. Nitrate of soda, however, has produced regular increases in yield.

On the limestone soil of the Pennsylvania State College, sulphate of ammonia gave larger increases than nitrate of soda for the first eight years of the test, but since the second 8-year period the ammonia salt has reduced the yields below those given by fertilizers containing no nitrogen, whereas the yields from nitrate of soda have steadily increased.

In the cereal rotations at Wooster and Strongsville sulphate of ammonia gave slightly greater increases than nitrate of soda for the first 10 years, but since that period nitrate of soda has been decidedly the more effective, on both unlimed and limed land.

The two crops which have thus far shown no unfavorable reaction to sulphate of ammonia are potatoes and tobacco, crops which are relatively indifferent both to soil acidity and to nitrogen fertilization when grown in rotation with clover, but the potatoes are being grown on limed land and the tobacco on soil of limestone origin.

The evidence from these tests therefore is conclusive that, although the first results from the application of sulphate of ammonia to the land may be altogether satisfactory, the continued use of this salt on land deficient in lime will ultimately result in loss of effectiveness unless this deficiency is corrected. This simply means that liming must be commenced earlier and continued more persistently if sulphate of ammonia is used in the fertilizer. It is not practicable altogether to avoid the necessity for liming by the use of nitrate of soda.

Sulphate of ammonia is more convenient to handle than nitrate of soda, requiring no sifting and pulverizing, and it is now sold at a lower price than nitrate of soda. For these reasons it is largely used as the carrier of nitrogen in mixed fertilizers, which makes it the more important that its possible effect should be understood.

The form of this salt known as "Arcadian" sulphate of ammonia contains less free sulphuric acid than that produced by the older methods of manufacture. This is the form used in the later Ohio experiments.

Various synthetic nitrogen compounds are being put upon the market, but have not yet been tested long enough to determine their relative value. Some of these resemble ammonium salts in their composition, while others more closely resemble nitrate of soda. Of the latter, nitrate of lime has been used for several years in Ohio experiments, with results closely approximating those given by nitrate of soda.[3]

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[3] In the Report of the Rhode Island Agricultural Experiment Station for 1893 Dr. H. J. Wheeler, then Chemist of the Station, called attention to the injurious effect of sulphate of ammonia when used on acid soil at that Station, and to the possibility of preventing this injury by the use of lime, this being the first observation of this effect published in America.

XX

Barnyard Manure

From time immemorial farmers have increased the yields of their fields by the use of animal excrement, and the advantage of growing leguminous crops in rotation with cereals was recognized by the earliest writers on agriculture. The parable of the fig tree, as related in Luke 13-8, shows that manuring was commonly practised at that date, and Theophrastus, who lived about 300 years earlier, is quoted as advising the growing of beans "to reinvigorate the ground."[1]

It was not until the earlier years of the Nineteenth Century that the progress of chemical science had begun to reveal the fact that the beneficial effect of manure is due chiefly to the nitrogen and mineral elements restored to the soil by its use, and that the growing of leguminous crops in rotation aids the cereals following by increasing the nitrogen supply.

Substitutes for manure—At an early date the discovery had been made that the growth of plants might sometimes be increased by burying broken bones within reach of their roots, and when the chemist had analyzed bone and found it composed largely of phosphorus the suspicion was awakened that this phosphorus, which he also found in manure and in all crops, was the secret of the fertilizing effect of bone. But he also discovered phosphorus in other substances, especially in a common rock known as apatite, and as has been stated above (p. 120) in 1843 a young English farmer, who had become interested in chemistry and not much else at Oxford, set about to convert this rock phosphate into a more available form, and thus established a new industry in the world—the manufacture of chemical fertilizers.

Nitrate of soda and the salts of ammonia and potash had been found to have useful fertilizing effects, and as manure was found to contain not only phosphorus, but nitrogen and potassium also, young Lawes began a series of field experiments in the comparison of these chemical substances with barnyard manure in the growth of wheat, barley and other crops on his ancestral estate of Rothamsted.

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[1] "The Microorganisms of the Soil," by Sir E. J. Russell, p. 5.

The use of substitutes for farm manure in America began with the importation of guano, which is the manure of seafowls, found on tropical islands where it has accumulated for centuries, and with the use of bonemeal and of the refuse from fisheries along the north Atlantic coast, the Indians having fertilized their cornfields with fish refuse before the advent of the whites; but it was not until after the Civil War that the deposits of phosphate rock in the southern states began to be drawn upon. About this time, also, the great slaughtering establishments that were being concentrated at Chicago and Kansas City began the conversion of their refuse into fertilizing material.

Probably not one farmer in a hundred of that day had any intelligent knowledge of the relation of chemistry to agriculture, even though he were a college graduate; for it was not until many years after Abraham Lincoln, in the midst of the Civil War, had signed the bill providing for the establishment of colleges in which the teaching of such relationships was to be a leading feature, that the leaven of such teaching had sufficiently permeated the educational system of the country to produce any effect upon agricultural practice.

Having become acquainted with the effect of bone and other fertilizers of animal origin, the farmer was easily led to believe that such fertilizers were superior to those made from rocks and salts, and of course the producers of the animal fertilizers took no pains to counteract this belief.

Dark colored soils had always been observed to be generally more productive than those lighter in color, and this darker color was correctly ascribed to the presence of organic matter derived from decaying vegetation; but vegetation is not animal matter, hence the term "organic matter" came into use as a comprehensive name for such substance, whether of vegetable or animal origin.

The composition of organic matter—The organic matter of soils and fertilizers consists of three groups of elementary substances: (1) nitrogenous compounds, in which nitrogen is found in the comparatively inert form of organic nitrogen, or in that of ammonia when carried in fermenting manure; (2) the various mineral elements found in plant or animal tissues; and (3) carbonaceous matter—starches, sugars, fats and cellulose—known collectively as carbohydrates, which go to make up the complete structure of the living organism.

The carbohydrates are complex combinations of carbon, hydrogen and oxygen, elaborated within the tissues of plants with green foliage, from the carbon dioxide of the atmosphere absorbed through the pores of the foliage and the hydrogen and oxygen absorbed by the plant roots, and combined under the influence of sunlight and of the green coloring matter—chlorophyll—of the foliage.

Carbohydrates not utilized as plant food—There is no evidence that such plants can make use of any more complex form of carbon than that of carbon dioxide, nor that the carbon dioxide which may be dissolved in the soil water and absorbed by the roots constitutes any important part of the supply of the plant.[2]

Apparently, the only surface-growing plants that require the organic combinations of carbon for their growth are the mushrooms and other parasitic plants destitute of chlorophyll.

Of the soil organisms that aid the plant roots in their collection of nutrient material the green algae, found on the surface, probably resemble other green plants in their dependence upon carbon dioxide. In the case of the organisms that are concerned in the decomposition of organic residues in the soil and in the fixation of atmospheric nitrogen in the

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[2] J. F. Breazeale has found carbonates in the ash of plants grown in free air in nutrient solutions containing carbonates of the mineral elements and nitrates, but when air was excluded there was practically no growth, from which he concludes that, while carbonates may be absorbed by the roots of plants growing in free air, yet the carbon needed for building up organic compounds in the plant is derived from the carbon dioxide of the air, and not from the carbonates taken into the plant through the roots. He suggests that the term "lime-loving," as applied to plants, might more properly be "carbonate-loving." (Journal of Agricultural Research, Vol. XXVI, No. 7, Nov. 17, 1923.)

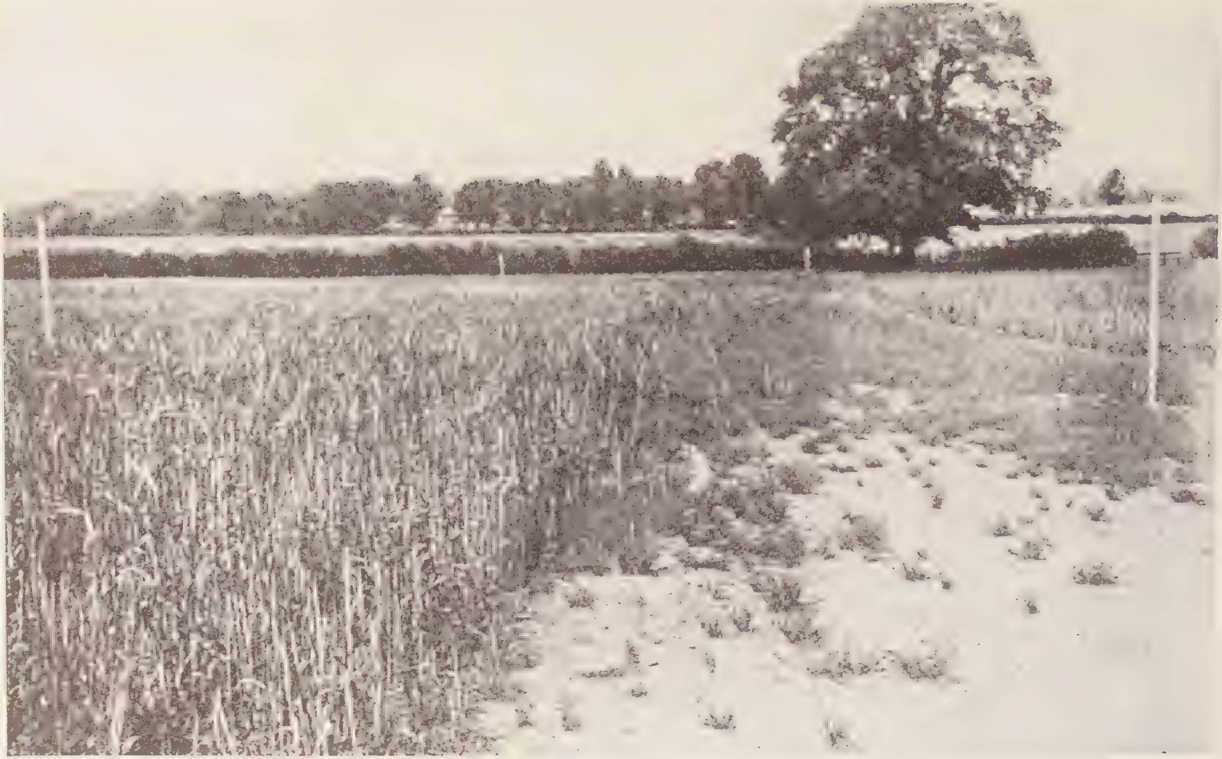

FIGURE XX.—EFFECT OF SULPHATE OF AMMONIA ON BARLEY AT WOBURN, ENGLAND

Left side, limed; right side, unlimed; both sides fertilized alike. From "Journal of the Royal Agricultural Society of England" absence of light, it is probable the carbohydrates are a more essential source of energy than with the algae, but such carbohydrates are furnished by the organic material under decomposition, and apparently the increased root growth that follows mineral fertilizing affords a sufficient quantity of carbohydrate for this purpose.

In short, the evidence seems to be conclusive that carbon dioxide is the one and sufficient source of carbon for ordinary crops, and that if the crop be fed with substances containing more complex combinations of carbon than this such substances will be broken down and their carbon recombined as carbon dioxide before it can be utilized in the growth of the crop. But the carbon dioxide thus added to the soil is infinitesimal in quantity, as compared with that which is constantly being returned to the atmosphere by the respiration of animal life and the consumption of fuels.

Composition of manure—It is extremely difficult to fix upon an estimate of the average composition of farm manure, because it is so greatly affected by differences in feed, in the digestive processes of the animals producing it, in exposure, and in proportions of litter and of moisture in the samples taken for analysis.

The manure used at Rothamsted is estimated to have contained, per ton of 2,000 pounds, 12.75 pounds of nitrogen, 2.19 pounds of phosphorus and 12.44 pounds of potassium.[3]

The manure used in the Pennsylvania experiments is estimated to have carried 9.8 pounds of nitrogen, 2.82 pounds of phosphorus and 7.14 pounds of potassium per ton, and is classed as "yard manure."[4]

At the Ohio Experiment Station J. W. Ames and his coworkers have made many analyses of manure from which they deduce the compositions shown in Table LVII as representing a general average for fresh manures, including solid and liquid excreta and litter, under ordinary farm conditions.

The manure from animals fed largely on grains—such as fattening cattle or swine—will be higher in nitrogen and phosphorus and lower in potassium than that from stock animals. Sheep manure usually carries less moisture than that from horses or cattle, while that from dairy cows is lower in the fertilizing elements than that from fattening cattle, because of the withdrawal of these elements in milk. Poultry manure contains less moisture than that from other farm animals, and may be roughly compared to sheep manure, except that, the food of poultry consisting chiefly of grain, the percentages of nitrogen and phosphorus will be higher and that of potassium lower in poultry manure than in that from sheep. Poultry manure is usually used in the air-dry condition, in which case the quantities of essential elements per 100 pounds of manure have been found to reach 1.8 pound nitrogen, 0.9 pound phosphorus and 0.8 pound potassium.

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[3] "The Book of the Rothamsted Experiments," London, J. Murray, 1905, p. 34: (recalculated).

[4] Penn. Ag. Exp. Sta. Bul. 175, Table I. 1920.

TABLE LVII.—COMPOSITION OF FRESH MANURE: POUNDS PER TON

MANURE FROM	*Nitrogen* (N)	*Phosphorus* (P)	*Phosphoric acid* (P_2O_5)	*Potassium* (K)	*Potash* (K_2O)
Horses	14	2.2	5.0	13	15
Steers	13.5	2.4	5.5	11	13
Dairy cows	11	1.9	4.4	10	12
Sheep	28	4.4	10.0	20	24

Comparison of manure with chemicals on crops grown continuously—Farmers have been accustomed to the use of manure at the rate of 10 to 20 tons per acre. When chemical fertilizers came into use they were usually applied at the rate of 200 to 300 pounds per acre. When the two classes of fertilizing materials were compared in such dressings as these the manure of course came out ahead, and the farmer, knowing nothing of the difference in actual composition of the two dressings, gave the credit to "organic matter" for the superiority of manure.

Not only farmers made this mistake. When young John Bennett Lawes began the field experiments, which have made the name of Rothamsted famous throughout the world of scientific agriculture, he used manure annually at the rate of 14 long tons per acre, equivalent to 15½ tons of 2,000 pounds, a dressing that was probably not considered excessive by the English or American farmer of that day;[5] but according to the analyses of his own laboratories this dressing contained 200 pounds of nitrogen, 34 pounds of phosphorus and 195 pounds of potassium. Alongside of this dressing he applied chemicals containing nitrogen in the three quantities of 43, 86 and 129 pounds, together with 28 pounds of phosphorus and 83 pounds of potassium—far larger quantities than are ordinarily given to the land in chemicals, and yet far below the manure dressing. The outcome is shown in Table LVIII.

TABLE LVIII.—FERTILIZING ELEMENTS APPLIED ANNUALLY TO EACH CROP AND YIELDS OF WHEAT AND BARLEY AT ROTHAMSTED FOR SEVENTY-FOUR YEARS, 1852-1925. ALL PER ACRE PER ANNUM.

CARRIER	*Fertilizing elements*			*Yield* [6]	
	Nitrogen	*Phosphorus*	*Potassium*	*Wheat*	*Barley*
	Lb.	*Lb.*	*Lb.*	*Bu.*	*Bu.*
Manure	200	34	195	33.5	45.1
Chemicals	129	28	83	34.5	...
Chemicals	86	28	83	30.4	...
Chemicals	43	28	83	...	39.9

The yield of wheat from the land receiving 129 pounds of nitrogen annually is the largest yield of wheat, considering the duration of the test, of which the world has any record, and yet this yield has been obtained without the addition to the land of an ounce of organic matter, excepting the stubble and roots of the wheat and the weeds that may have grown in or following the wheat, but weeds cannot have found much room in a growth of wheat averaging nearly 35 bushels per acre, and as wheat is not harvested in this latitude until August there has been too little time left for any such growth of weeds as sometimes follows the harvest on American wheatfields.

The barley has received only the smallest application of chemical nitrogen, and while its yield has been less than that from manure, the difference is smaller than from the corresponding treatments of wheat.

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[5] In the writer's boyhood twenty loads per acre, probably about fifteen tons, was the ordinary dressing of manure on the Ohio farms with which he was acquainted.

[6] In English bushels.

The chemicals in this test have been the sulphate and chloride of ammonia, superphosphate, and the sulphates of potash, soda and magnesia, thus carrying back to the land not only nitrogen, but also sodium, sulphur, chlorine, calcium and magnesium, all of which are found in plants and in manure.

The sum of the three elements, nitrogen, phosphorus and potassium, has been 429 pounds for the manured land and 240 pounds for the land receiving chemicals. Probably, as will be shown further on, there has not been sufficient allowance in the Rothamsted estimate for loss of nitrogen between the stable and the field, but if we compute the effective nitrogen in the manure at 9 pounds per ton of 2,000 pounds the sum would still be more than 50 percent greater for manure than for chemicals.

The question may be raised, whether the sulphates of soda and magnesia may not have given considerable advantage to the chemicals. In another part of the same test these salts have been omitted, with a yield of 1.2 bushel per acre below that of the land receiving them together with the same treatment in other respects.

Another question is of greater importance, namely: whether both manure and chemicals have not been used in this test in such excessive quantities as to obscure the comparison, for if the smallest dressing of fertilizing materials be more than the plant has growth capacity to utilize, any additional quantity will be wasted. This question has been partly answered by the smaller yields following the smaller applications of nitrogen, but a further answer is given in the Ohio experiments, which were begun nearly 40 years later, and in which wheat, oats and corn have each been grown continuously for the 35 years, 1894-1928, with the outcome shown in Table LIX, which gives the yields obtained from annual dressings per acre of 2½ tons and 5 tons of manure, and from nitrate of soda, superphosphate and muriate of potash, carrying the elements stated in the table.

The manure used in this test has been the ordinary mixed manure of the open barnyard, where it has received daily accretions of fresh manure. The ordinary estimate for such manure is 10 pounds of nitrogen per ton of manure. It is computed in Table LIX at 9 pounds. Whichever estimate be accepted, it is evident that the chemical fertilizers have been at least as effective, pound for pound of total elements contained, as the manure.

TABLE LIX.—COMPARATIVE EFFECT OF MANURE AND CHEMICALS ON CROPS GROWN CONTINUOUSLY IN OHIO. TREATMENT AND YIELD PER ACRE PER ANNUM FOR THIRTY-FIVE YEARS

		Elements in treatment				
Plot No.	*Treatment*	*Nitrogen* *Lb.*	*Phosphorus* *Lb.*	*Potassium* *Lb.*	*Total* *Lb.*	*Yield* *Bu.*
			Wheat[7]			
5	Manure	22.5	5.5	17.5	45.5	14.67
3	Chemicals	25.0	4.2	12.0	41.2	14.96
6	Manure	45.0	11.0	35.0	91.0	19.42
9	Chemicals	50.0	8.4	24.0	82.4	20.30
			Oats			
5	Manure	22.5	5.5	17.5	45.5	29.44
3	Chemicals	25.0	3.8	20.5	49.3	36.42
6	Manure	45.0	11.0	35.0	91.0	37.82
9	Chemicals	50.0	8.4	41.0	99.4	46.27
			Corn[7]			
5	Manure	22.5	5.5	17.5	45.5	22.93
3	Chemicals	25.0	8.8	12.0	40.8	30.41
6	Manure	45.0	11.0	35.0	91.0	32.56
9	Chemicals	50.0	8.4	24.0	82.4	40.63

Corn is generally assumed to be especially responsive to organic matter—black soils are usually found to be peculiarly favorable to this crop—and the Ohio experiments are showing that it is more responsive to potassic fertilizers than wheat; but in this test the chemicals are showing a greater superiority for corn than for wheat, and the test fully confirms that at Rothamsted in showing that manure owes its fertilizing value to the nitrogen and mineral elements contained.

Comparative effect of manure and chemicals on crops grown in rotation—In the 40-year test at the Pennsylvania Experiment Station manure, classed as "yard ma-

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[7] All the land in wheat and half that in corn have had occasional limings. The results given for corn are the averages for limed and unlimed land.

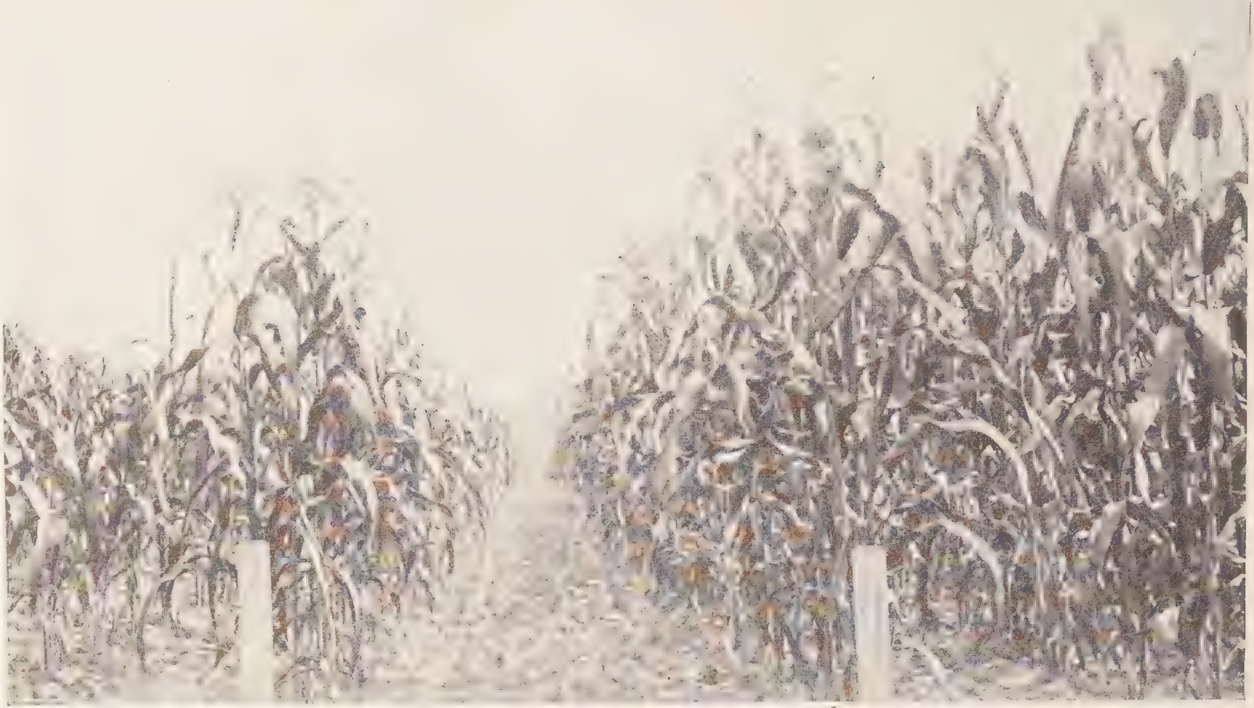

FIGURE XXI.—CORN IN MANURE TEST, OHIO EXPERIMENT STATION

Plot 4, left, no treatment. Plot 5, right, stall manure and superphosphate.

nure," used in the three quantities of 6 tons, 8 tons and 10 tons per acre, and chemical fertilizers, made up of superphosphate, muriate of potash and nitrate of soda, the nitrate also being used in three quantities, are each used on corn and wheat in the 4-year rotation of corn, oats, wheat and clover. The outcome of this test for the first 25 years and the next 15 years of the test is shown in Table LX which gives the estimated quantities of nitrogen, phosphorus and potassium in each treatment, the increase produced and its value, using the valuations hereinbefore employed.

Table LX shows that the manure has carried more nitrogen and less potassium than the chemicals, and that the smallest dressing of manure has carried less phosphorus than the chemicals. It is therefore impossible to make an exact comparison between the two treatments on the chemical basis.

In the final column of the table the value of the increase is computed both per acre and per pound of fertilizing elements, a method of computation that would be legitimate if the three elements, nitrogen, phosphorus and potassium were equal in cost and effectiveness. During the first period of the test it would seem that there has been but little difference in this respect in the small and medium dressings, but the large dressing of manure has been considerably less effective per unit than the large chemical dressing.

During the second period the falling off in yield of the unfertilized land shows that the soil reserves have been much reduced, and the demand for nitrogen becomes more urgent. Plot 26, with 12 pounds of nitrogen, falls behind Plot 16, with 29 pounds, and Plot 28, with 36 pounds, is overtaken by Plot 20, with 49 pounds. What would have happened if Plot 28 had received as much phosphorus as Plot 20 can only be conjectured.

Experience has shown that in such tests as this there is more or less play in the effects of the different fertilizing elements. The materials employed in compounding the fertilizer used on Plot 26 have been used separately, but in the same quantities, on Plots 2, 3 and 4, and in combination on Plots 9 and 17, except that the nitrogen has been carried in dried blood instead of nitrate of soda, with the outcome that

TABLE LX.—COMPARATIVE EFFECT OF MANURE AND CHEMICAL FERTILIZERS IN THE CROP ROTATION AT THE PENNSYLVANIA EXPERIMENT STATION. TREATMENT, UNTREATED YIELD AND INCREASE PER ACRE PER ANNUM

Plot No.	*Treatment*	*Fertilizing elements*				*Untreated yield and increase*				*Value of increase*		*Plot No.*
		Nitrogen Lb.	*Phosphorus Lb.*	*Potassium Lb.*	*Total Lb.*	*Corn Bu.*	*Oats Bu.*	*Wheat Bu.*	*Hay Cwt.*	*Per acre Dol.*	*Per lb. element Cts.*	
					25 years, 1882-1906							
	None	..	..	..	..	40.1	32.1	14.0	26.7	...	...	
	(Increase)											
16	Manure	29	8	21	58	17.4	7.6	8.7	12.1	8.96	15.4	16
18	Manure	39	11	28	78	13.4	9.3	9.5	14.8	9.03	11.6	18
20	Manure	49	14	35	98	16.0	9.3	9.9	14.5	9.63	9.8	20
26	Chemicals	12	11	41	64	16.8	8.6	8.9	15.6	9.55	14.9	26
27	Chemicals	24	11	41	76	16.6	9.8	10.2	16.3	10.23	13.6	27
28	Chemicals	36	11	41	88	16.9	9.6	11.0	15.9	10.40	11.8	28
					15 years, 1907-1921							
	None [8]	..	..	..	..	26.9	29.6	11.9	16.7	...	...	
	(Increase)											
16	Manure	29	8	21	58	27.4	16.5	13.8	20.1	14.87	25.6	16
18	Manure	39	11	28	78	29.5	16.1	14.3	23.8	15.95	20.4	18
20	Manure	49	14	35	98	33.1	19.8	17.4	27.3	18.63	19.0	20
26	Chemicals	12	11	41	64	30.5	18.8	11.8	22.7	15.54	24.3	26
27	Chemicals	24	11	41	76	32.7	19.2	13.9	20.6	16.37	21.5	27
28	Chemicals	36	11	41	88	33.6	18.0	15.5	22.3	17.16	19.5	28

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[8] Average yields of Plots, 14, 24 and 36.

the sum of the increases from the three dressings has been worth $8.16 per acre during the first period and $10.89 during the second, while the average value of the combined dressing on Plots 9 and 17 has been $9.55 for the first period and $15.54 for the second. In the Ohio experiments a similar comparison has given $10.02 for the sum of the separate dressings, as against $15.90 for the combined dressing.[9] We have grounds for assuming, therefore, that within certain limits the use of the total sum of fertilizing elements in comparing the effect of different combinations of fertilizing materials is legitimate, but evidently there must be a limit to such use.

In the next table the end results of the Pennsylvania test are rearranged for more convenient comparison in the order of total fertilizing elements applied.

TABLE LXI.—SUMMARY OF TABLE LX

PLOT No.	*Treatment*	*Total elements*	*Value of increase per pound of elements*	
			First 25 years	*Last 15 years*
		Lb.	*Cts.*	*Cts.*
16	Manure	53	15.4	25.6
26	Chemicals	64	14.9	24.3
27	Chemicals	76	13.6	21.5
18	Manure	78	11.6	20.4
28	Chemicals	88	11.8	19.5
20	Manure	98	9.8	19.0

Table LXI indicates that the law of diminishing returns has had more to do with the relative effects of the different treatments than the carrier of the fertilizing elements, the value of increase per pound of elements being in inverse ratio to the number of pounds of these elements in the fertilizer or manure.

This comparison, of course, does not indicate the relative profit per acre resulting from the different treatments,

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[9] When the Pennsylvania test was planned the importance of frequent repetition of check plots had not been demonstrated, and only five such checks were left in a total of forty plots. As the work has progressed it has become evident that one of these checks, No. 8, was abnormal and it has been necessary to reject it. The writer has recalculated the results of this test, using the check plots, except Numbers 1 and 8, and the increases given are deduced from this calculation. —C. E. T.

TABLE LXII.—COMPARATIVE EFFECT OF MANURE AND CHEMICALS IN THE CROP ROTATIONS OF THE OHIO EXPERIMENT STATION. UNTREATED YIELDS AND AVERAGE ANNUAL INCREASE PER ACRE

Plot No.	Treatment	Fertilizing elements				Untreated yields and increase					Value of increase	
		Nitrogen Lb.	*Phosphorus Lb.*	*Potassium Lb.*	*Total Lb.*	*Corn Bu.*	*Oats Bu.*	*Wheat Bu.*	*Clover Cwt.*	*Timothy Cwt.*	*Per acre Dol.*	*Per lb. element Cts.*
	Wooster, 35 years, limed land											
	Untreated	..	..	..	..	31.0	34.7	12.9	18.6	28.0	...	..
	(Increase)											
18	Manure	29	7.0	22	58	28.6	12.1	14.7	23.1	19.2	14.55	25
12	Chemicals	23	6.0	22	51	24.3	17.8	17.9	16.5	9.7	13.29	26
20	Manure	14.5	3.5	11	29	16.2	7.3	9.3	12.5	11.1	8.48	29
14	Chemicals	10	3.5	15	28.5	18.6	8.6	14.2	9.7	5.7	9.24	32
	Strongsville, 33 years, limed and raw phosphate treated land											
	Untreated	..	..	..	..	27.3	37.2	12.0	20.1	[10] 24.0	...	..
	(Increase)											
18	Manure	29	7.0	22	58	15.0	8.7	8.6	11.1	[10] 6.6	7.54	13
12	Chemicals	23	6.0	22	51	14.5	17.1	14.5	9.2	[10] 3.4	9.17	18
20	Manure	14.5	3.5	11	29	9.7	5.4	5.3	7.4	[10] 4.7	4.87	17
14	Chemicals	10	3.5	15	28.5	8.8	4.8	11.5	7.2	[10] 3.2	6.01	21
	Germantown, 24 years, limed land											
	Untreated	..	..	..	..	39.6	...	11.1	21.5	..	...	..
	(Increase)											
17	Manure	15.5	3.9	18.6	38	19.3	...	5.5	7.7	..	9.00	24
15	Chemicals	16.5	10.4	11.1	38	21.0	...	11.9	12.0	..	12.97	34
29	Manure	15.5	8.9	18.6	43	19.9	...	9.1	9.4	..	11.02	26
	Carpenter, 24 years, limed land											
	Untreated	..	..	..	..	23.7	...	8.2	10.5	..	...	..
	(Increase)											
17	Manure	15.5	3.9	18.6	38	17.8	...	10.4	11.1	..	11.32	30
15	Chemicals	16.5	10.4	11.1	38	21.4	...	12.5	16.2	..	14.16	37
	Wooster Annex, 14 years, limed land											
	Untreated	..	..	..	..	53.5	53.1	23.7	34.6	..	...	..
	(Increase)											
29	Manure	9	2	6	17	8.9	3.9	1.5	3.6	..	3.29	19
26	Chemicals	9	2	6	17	10.3	5.9	3.2	2.5	..	4.17	24
30	Manure	9	10	6	25	14.1	7.7	7.5	5.9	..	7.02	28
27	Chemicals	9	10	6	25	14.4	9.7	8.1	8.2	..	7.85	31

[10] 10 crops.

as the larger total gain from a large dressing, or the lower cost of manure, may more than offset the lower relative gain per pound of element.

The Ohio experiments afford eight comparisons between the use of manure and chemicals in rotative cropping: two each in the rotations at Wooster and Strongsville, and one each in the 3-year rotations at Germantown and Carpenter. The outcome in these tests is shown in Table LXII.

In the tests at Wooster and Strongsville Plot 12 received only four pounds of phosphorus per acre annually until 1921, when the quantity was increased to 13 pounds, making an average of nearly six pounds for the 35 years. The prompt response to this increase leaves little room to doubt that if the quantity had been made six pounds at the outset the 35-year average yield of this plot would have been considerably greater than that shown in the table.

On the other hand, the oats crop has received no direct treatment on the manured land, whereas this crop has received a part of the chemical fertilizer on Plot 12.

On Plots 20 and 14, both manure and chemicals are divided between corn and wheat, the oats being left untreated.

In the three-year rotations both manure and chemicals have all been given to the corn, and the wheat has been limed. The increase shown includes the effect of the liming in these tests. In the Wooster tests the land has had a basic liming, the effect of which is not included in the increases shown. In the Strongsville test half the land has had a basic dressing of limestone and the other half one of raw phosphate, which has reduced the apparent effect of phosphorus in the fertilizers. The increases shown are those in excess of the yields due to the basic dressings.

The larger dressing of manure in the Ohio 5-year rotations has carried practically the same annual quantity per acre of the fertilizing elements as the smallest one in the Pennsylvania test, and the smaller one in Ohio, half as much. The chemical dressings have been correspondingly smaller, and consequently there has been a more complete utilization of the fertilizing elements at Wooster. The smaller utilization at Strongsville is due in part to the basic dressing of raw phosphate and in part to the low response of the Strongsville soil to potassic fertilization.

The final comparisons shown in Table LXII have been running 14 years in a four-year rotation of corn, oats, wheat and clover, a test that was planned in the light of previous experience, which had demonstrated that in crop rotations in which clover is grown systematically, much of the nitrogen carried in manure will be wasted unless the manure is supplemented with phosphorus. In this test, therefore, the manure is applied at the rate of four tons per acre—alone on Plot 29, but after being reinforced with superphosphate on Plot 30—while chemical fertilizers are made up to correspond in composition with the manure dressings and all are applied to the corn crop alone.

The manure used in this test has not been exposed to the weather and is therefore of better quality than ordinary farmyard manure. The outcome shows a wide difference in effectiveness between the low phosphorus and high phosphorus treatments for both manure and chemicals.

Three questions of importance in the study of this problem remain to be considered, namely: (1) Is not the effect of manure more permanent than that of chemicals?

(2) Will not manure carry the crop through bad seasons better than chemicals? and

(3) Does not manure assist in conserving moisture and otherwise improve the physical condition of the soil to a greater extent than chemicals?

Relative permanence of effect of manure and chemicals—The first of these questions is considered in Table LXIII, in which the increases found in the 5-year rotations at Wooster and Strongsville are arranged in two periods, the first being the 10 years before liming was begun, the second being the 10 years 1919-1928 at Wooster and 1918-1927 at Strongsville, the results being shown for the limed land at Wooster and averaged for the limed and raw-phosphate-treated land at Strongsville, the phosphate treatment, however, having been discontinued in 1913.

Table LXIII shows that the chemicals have produced larger increases in the grain crops than the manure in 21 of the 24 comparisons, the three exceptions being relatively small differences in the corn.

The clover has given larger increases after manure in six of the eight comparisons, and the timothy and soybean hay have shown larger increases after manure in every case.

The average value has been greater after the chemicals than after the manure in every comparison except during the second period at Wooster, where the large superiority of the manured timothy has thrown the balance the other way.

The apparent explanation of this outcome is that manure and other organic materials are slower in getting into action than such chemicals as have been used in these tests, and hence a larger proportion of the total effect of manure is carried forward to the later crops in the rotation than is the case with chemicals. This is especially true of nitrogen. Bacteriological studies have shown that organic nitrogen and ammonia must first be converted into nitrate before they become available to such crops as are here under consideration, conclusions that are verified by both the Pennsylvania and Ohio experiments, in which the organic nitrogen of dried blood has been less effective than that of sulphate of ammonia, and that of the ammonia salt less so than that of nitrate of soda.

The relatively greater response that has been shown to manure by corn than by the small grains is presumably due to the fact that corn makes its growth chiefly during the hot months, when nitrification is most active in the soil, and the corn is thus able to utilize nitrates that are formed after the small grains have made the larger part of their growth.

This fact is a further explanation of the greater response of timothy to manure than to chemicals, for nitrate nitrogen must be utilized promptly upon its liberation from its combinations or it will escape into the atmosphere, hence it is probable that the nitrate of soda used in these experiments has only affected the timothy indirectly, its nitrogen having first been consumed by the preceding crops, and only the small quantity fixed in their roots and stubbles being carried forward to the timothy; whereas a part of the nitrogen of manure is undoubtedly carried forward in the partially decomposed fibrous matter of the manure.

TABLE LXIII.—COMPARATIVE EFFECT OF MANURE AND CHEMICALS IN FIVE-YEAR ROTATIONS AT WOOSTER AND STRONGSVILLE BY PERIODS: TREATMENT, UNTREATED YIELDS AND INCREASE PER ACRE PER ANNUM

Plot No.	Treatment	*Fertilizing elements*				*Untreated yield and increase*					*Value of increase*	*Plot No.*
		Nitrogen	*Phosphorus*	*Potassium*	*Total*	*Corn*	*Oats*	*Wheat*	*Hay*			
									Clover	*Timothy*		
		Lb.	*Lb.*	*Lb.*	*Lb.*	*Bu.*	*Bu.*	*Bu.*	*Cwt.*	*Cwt.*	*Dol.*	
					Wooster, first 10 years, 1894-1903, unlimed land							
	Untreated (Increase)	..	..	..	..	31.4	29.6	8.9	16.3	23.9	...	
18	Manure	29	7	22	58	14.7	9.0	7.7	13.5	10.2	8.02	18
12	Chemicals	23	4	22	49	15.9	18.9	15.9	11.6	5.1	10.43	12
20	Manure	14.5	3.5	11	29	10.0	5.8	4.8	8.3	7.8	5.30	20
14	Chemicals	10	3	15	28	14.3	7.7	13.0	9.0	5.4	8.05	14
					Wooster, last 10 years, 1919-1928, limed land							
	Untreated (Increase)	..	..	..	..	31.3	37.4	14.4	20.8	28.8	...	
18	Manure	29	7	22	58	37.3	12.4	18.8	26.9	22.4	17.84	18
12	Chemicals	23	13	22	58	36.7	16.6	19.8	19.7	9.3	15.96	12
20	Manure	14.5	3.5	11	29	22.2	7.2	11.8	15.6	12.8	10.64	20
14	Chemicals	10	4	15	29	23.7	8.3	14.1	8.8	4.3	9.72	14
					Strongsville, first 10 years, 1895-1904, unlimed land							
	Untreated (Increase)	..	..	..	..	32.5	34.8	5.6	13.2	8.3	...	
18	Manure	29	7	22	58	12.2	7.2	9.0	7.6	4.6	6.38	18
12	Chemicals	23	4	22	49	10.1	14.8	12.8	7.2	2.7	7.50	12
20	Manure	14.5	3.5	11	29	7.8	4.0	4.9	6.1	3.6	4.04	20
14	Chemicals	10	3	15	28	8.8	5.5	10.8	7.1	3.0	5.88	14
					Strongsville, last 10 years, 1918-1927, limed and raw phosphate-treated land							
	Untreated (Increase)	..	..	..	..	28.6	40.6	18.1	20.1	[11]23.6	...	
18	Manure	29	7	22	58	17.5	11.3	9.4	13.5	[11]7.6	8.80	18
12	Chemicals	23	13	22	58	19.6	21.9	18.8	12.0	[11]2.6	11.82	12
20	Manure	14.5	3.5	11	29	12.4	7.9	5.7	7.6	[11]4.1	5.59	20
14	Chemicals	10	4	15	29	10.1	5.4	13.9	7.1	[11]3.8	6.93	14

[11] Soybean hay

The evanescent effect of chemical carriers of nitrogen is shown in that part of Broadbalk Field in which two plots receive the same basic dressing of mineral fertilizers but get ammonia salts only in alternate years, the outcome being a 74-year average increase over the land which receives the same minerals but never any nitrogen of 2.4 bushels per acre for the years when no nitrogen is given, as against 16.1 bushels for the nitrogen years, showing that none of the fertilizer nitrogen is carried forward to the succeeding crop except that stored in the roots and stubble.

The effect of manure, therefore, is of longer duration than that of chemicals merely because the same total effect is spread over a longer period of time.

Manure vs. Chemicals in bad seasons—There have been three seasons each for corn and wheat, during the course of the experiments at Wooster, when the yields were reduced much below the average by unfavorable climatic conditions. In 1910 the May temperature was abnormally low, with a heavy frost on the 6th and cold, rainy weather following which continued until near the middle of June, thus delaying the planting. The rains then ceased, the total rainfall between that time and the end of September being only 2½ inches, as against a normal rainfall for this period of 10 inches. In 1924 and 1927 May and June were again wet and cold, delaying the planting, but the rainfall was normal during the summer months. Table LXIV shows that under the conditions of late planting followed by drought, which prevailed in 1910, manure was distinctly superior to chemicals in increasing the yield of corn, but that with normal rainfall the outcome was reversed, the chemicals producing the greater increase in three of the four comparisons.

The winter of 1911-12 was one of the coldest recorded in Ohio, the mean temperature being 6 to 10 degress below normal through January, February and March and falling to 30 degrees below zero on January 13. The consequence was that nearly half the wheat acreage of the state was abandoned and the remainder averaged only about half the normal yield per acre. January 1920 was described by the State Weather Bureau as being one of the coldest months in its history, the cold extending into February. During the greater part of both months the ground over much of northern Ohio was covered with a sheet of ice which smothered much of the wheat. This was followed by deficient precipitation through February and March, and the wheat could not recover from the winter injury. The winter of 1927-28 was one of abnormally high temperature; the occasional snows were soon melted, leaving the wheat unprotected from the March-like weather, with alternate freezing and thawing, that prevailed throughout the winter. The consequence was one of the most complete wheat failures Ohio has ever experienced, the major part of the wheat land being sown in the spring to oats or barley. Table LXIV shows that in 1912 and 1920 the yield of wheat was a little better under the larger dressing of manure than with the larger dose of chemicals, but under the smaller dressings of manure and chemicals, and in 1928 in both comparisons, the chemical-treated wheat came out ahead.

Table LXIV.—Comparative Effect of Manure and Chemicals in Bad Seasons. Unfertilized Yields and Increase From Treatment in Bushels per Acre

	Crop and treatment	*Year and Range*					
		Unlimed			*Limed*		
Plot	*Corn*	*1910-E*	*1924-D*	*1927-A*	*1910-E*	*1924-D*	*1927-A*
	Unfertilized yield ...	5.61	1.02	6.68	7.79	9.08	34.79
	(Increase)						
18	Manure, 8 tons	32.23	19.51	59.53	29.43	34.19	60.72
12	Chemicals	5.10	22.29	42.97	10.38	50.04	65.33
20	Manure, 4 tons	10.36	6.00	24.50	18.07	16.74	41.02
14	Chemicals	5.10	11.39	41.88	7.67	25.26	46.02
	Wheat	*1912-E*	*1920-C*	*1928-B*	*1912-E*	*1920-C*	*1928-B*
	Unfertilized yield ...	.74	2.11	2.73	1.35	7.72	9.67
	(Increase)						
18	Manure, 8 tons	7.39	18.11	11.42	12.14	19.36	12.08
12	Chemicals	5.61	16.75	10.56	11.01	13.08	17.36
20	Manure, 4 tons	3.94	9.28	6.47	6.39	13.31	6.94
14	Chemicals	7.55	13.36	23.53	8.45	14.00	12.23

Insofar as these experiences may be taken as a guide, therefore, we must conclude that the only abnormal weather condition under which manure will prove superior to chemicals is that of deficiency in rainfall, and the 35-year average results, as recorded in the preceding tables, show that this condition has occurred so rarely as to have no importance in the solution of the problem under consideration.

Effect of manure on the physical condition of the soil—There can be no question that manure or other fibrous material will improve the texture of the soil and increase its capacity to retain moisture, provided it is used in sufficient quantity. The experiments reported in Table LXIV indicate that the larger dressing, of 16 tons of manure per acre for each 5-year period, has had a slight effect in this direction. When, however, the dressing is reduced to half that quantity, or to five tons every three years, it is difficult to discover a sufficient advantage to justify its use for this purpose in preference to chemical fertilizers, in the production of ordinary farm crops.

In market gardening manure is employed for this purpose as much as for the plant food it contains, 40 tons or more per acre being frequently applied, but the use of such a quantity is impracticable in ordinary farming.

Moreover, it must not be forgotten that no practicable use of manure on the farm will so completely incorporate organic matter with the soil as will the growth of a good crop of clover, even though the hay be removed from the land; but under the conditions that prevail in market gardening, when the value of the land itself may exceed $1,000 an acre in outdoor gardening, or $20,000 when covered with glass, the growing of clover for soil improvement would be less practicable than would be the use of 40 tons of manure on the farm.

CONCLUSIONS

For unnumbered centuries the use of the manure of the farmyard has been the standard by which all other methods for maintaining the fertility of the land are measured.

Every man who has ever followed the plow has observed that the darker soils are usually more productive than those of lighter color, and he has rightly ascribed this superiority to the greater proportion of organic material in the darker soils.

Knowing that manure is of organic origin, and observing that the soil is darkened by liberal use of manure, the conclusion has been reached that manure is of superior value because of its organic origin.

When manure has been compared with chemical fertilizers the manure usually has been used in such amounts as to carry far larger quantities of the essential elements of fertility than those given in the chemicals and, without stopping to consider this point, the carbonaceous matter of the manure has been credited with the superior effect produced.

So firmly has the idea become fixed in the average mind that manure possesses fertilizing properties additional to those due to its chemical constituents, that the suggestion that chemicals may be so employed as to equal the effect of manure, pound for pound of nitrogen and mineral elements contained, has been taken as an attempt to depreciate the value of manure.

What the experiments described in the foregoing chapter are believed to teach is that manure, as used in ordinary farm practice, owes its value to the nitrogen and inorganic elements contained, and that, by employing manure in the light of the knowledge which modern science has given us we may very greatly increase its value. This problem will be further considered in the next chapter.

XXI

The Production, Conservation and Reinforcement of Manure

It is obvious that the feed consumed and the materials used for litter will determine the quantity of manure produced, and that its quality will depend on the amount of nitrogen and essential mineral elements recovered after the feed has served its purpose in the support and growth of the animal and the production of milk and wool.

Elements of feed recovered in manure—At the Ohio Experiment Station, E. B. Forbes and his associates fed five pigs for 80 days and four pigs for 50 days under such conditions that all the feces and urine were collected separately. They also fed six cows under similar conditions during three successive years, a different lot each year, in periods of 60, 40 and 40 days. In both series of experiments the amounts and chemical composition of the feeds and excreta were determined. The average percentage recovery and distribution of the nitrogen, phosphorus and potassium contained in the feed are shown in Table LXV.[1]

The pigs used in these experiments were growing rapidly and the outcome shows that 28 percent of the nitrogen and 17 percent of the phosphorus contained in their feed were utilized in support of this growth—the phosphorus chiefly in the skeleton, the nitrogen in that and in the muscular and other tissues.

The cows were mature animals, Holstein or Holstein grades, and in the first part of their lactation periods. There was but little change in their live weights or in their flow of milk during the tests. The table shows that practically the same percentage of nitrogen was found in the milk as in the growth of the pigs, but the milk carried more than twice the relative proportion of phosphorus and just twice that of potassium found in the growth of the pigs, leaving a much smaller proportion of these elements in the manure from the cows than in that from the pigs.

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[1] Compiled from Bulletins 271, 283, 295, 308 and 330 of the Ohio Ag. Exp. Station.

The negative balance for phosphorus with the cows apparently means that the bones had been temporarily drawn upon to maintain the supply of this element in the milk, and explains the necessity for giving the cow a resting period between lactations to recover this loss. The cows were not bred during these tests.

Table LXV.—Recovery and Distribution of Fertilizing Elements Contained in the Feed

Distribution	*Percentage recovery* *Nitrogen*	 *Phosphorus*	 *Potassium*
	From pigs		
In feces	21	60	35
In urine	51	23	55
Total recovery	72	83	90
Balance (in growth)	28	17	10
	From cows		
In feces	40	63	17
In urine	28	1	61
In milk	29	40	20
Total recovery	97	104	98
Balance (in growth)	3	—4	2

Proportion recovered in solid and liquid excreta—A point of special importance is the relatively large proportions of the nitrogen and potassium of the feed that pass out through the urine. With pigs, more than three-fourths of the recoverable nitrogen and about four-fifths of the potassium, and with cows, nearly one-third the nitrogen and two-thirds the potassium pass out through this channel.

When, therefore, manure is produced over earth or loose plank floors there will be a very considerable loss of its useful constituents, not only in quantity but in quality, for the liquid portion will be the first to be lost, and the constituents of this portion, being already in solution, are the most readily available.

At the same station two lots of steers, 30 in one lot and

28 in the other, were fed for 6 months, the one lot on an earth floor that had been compacted by several years use and the other on a cemented floor. On the earth floor, 62 percent of the nitrogen contained in the feed, 79 percent of the phosphorus and 78 percent of the potassium were recovered in the manure; on the cement floor, the recovery was 75 percent of the nitrogen, 78 percent of the phosphorus and 88 percent of the potassium, the relative recovery of phosphorus on the earth floor being greater because that element is excreted chiefly in the feces of cattle, as shown in Table LXV.

The total recovery of manure was six pounds per steer per day greater on the cemented than on the earth floor, or half a ton per steer for the six months of the test.[2]

Cow stables have been constructed with drains leading from trenches behind the cows to cement cisterns, but the separate application of the liquid not only involves additional labor and distributing machinery, but this portion is so low in phosphorus that, unless heavily reinforced with that element, it will be used wastefully on the majority of soils. The more practicable method is to use absorbent litter liberally and collect the mixed solid and liquid excrement in the carriers now in common use and convey directly to the field, or to a storage shed when for any reason immediate application is not practicable.

Sources of losses of manure—It is very difficult so to handle manure that there shall not be some loss of its nitrogen. If piled in heaps fermentation soon begins, with development of heat, and the smell of ammonia when the heap is stirred is evidence that nitrogen is escaping. When spread upon the field there is some ammonia carried away in the moisture of evaporation as the manure dries, a loss that will be greater from manure that has been heaped until fermentation has been set up and then spread than if it be moved directly from the stable to the field. In other words, every time manure is handled there is an additional loss of nitrogen.

One of the most wasteful methods of handling manure is to pile it in small heaps over the field, leaving the heaps for several weeks for fermentation to get under way and for the

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[2] Ohio Exp. Sta. Bul. 183, by J. W. Ames and E. W. Gaither.

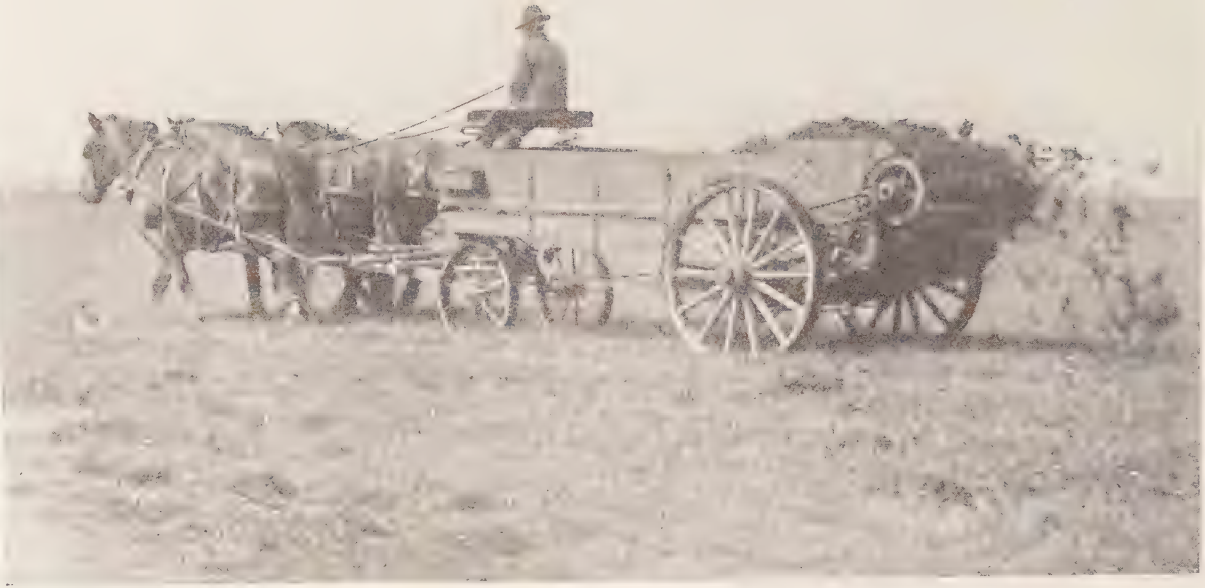

FIGURE XXII.—SPREADING MANURE

Manure, phosphorus, lime and clover, the quadruple key to the economical maintenance of fertility. Spreading phosphated manure in September on the clover sod which is to be planted to corn the following spring, after plowing under the manure and applying two tons per acre of powdered limestone to the plowed surface. See Figures XXVII and XXVIII for the outcome. Photo by E. J. Houser.

rain to wash not only the escaping ammonia but also the more soluble portions of the mineral elements into the small area covered by the heap. Probably the greatest advantage in the manure spreader is that it is not adapted to this method of management.

While, therefore, there is some loss of ammonia from manure that is carried directly from the stable to the field and spread on the surface at once, this loss, in humid climates, is smaller than that following any other method of handling, because the rains will carry part of the escaping ammonia and all of the mineral elements directly into the soil where their work is needed.

Spreading manure on hillsides—The question is frequently raised whether manure spread on hillside land during the winter will not suffer serious loss from washing. That question is partly answered by the experiment described in the following chapter. While the land employed in this experiment is not steep, it is sufficiently inclined to permit the ready outflow of surface water, which is further facilitated by a slight ridging of the plots, and the outcome shows that whatever loss may have been due to surface washing in the field, in the average season it has been greatly exceeded by the vertical washing in the barnyard.

The manure shed—The chief function of the manure shed would seem to be the protection of the manure when it is not practicable to take it at once to the field, either because no field for the time being is ready to receive it, or because the soil may not be in condition to be driven upon, as during the spring thaw or when the ground is soaked with rain; but under the shed there will be some heating and escape of ammonia, a loss that can be reduced to some extent by keeping the manure well compacted and dusting it with superphosphate.

One of the most neglected portions of many farms, and one which would give prompt and profitable response to better treatment, is the permanent pasture, which is always ready to receive the manure spreader except when the ground is softest. Under systematic planning provision would be made for sending the manure to the pasture when other fields are not available.

The experiments reported in this chapter illustrate the general principle that growing animals, or those producing milk, withdraw from their feed a larger proportion of the essential elements of fertility than do mature animals, and that dairying, especially, may be one of the most exhaustive systems of husbandry if provision be not made for the systematic conservation of manure and its reinforcement with phosphorus.

It is no accident that the great dairy region of Ohio, the northeastern counties, should be the area in which artificial phosphates first made their appearance and have maintained their strongest foothold.

The reinforcement of manure—Attention has already been called to the fact that, in ordinary systems of agriculture, the soil is depleted of its phosphorus more rapidly than of its potassium, most of the phosphorus in crops being carried away in the grains, or in the bones and milk of animals fed on the farm, while the major part of the potassium remains behind in the straw and manure. A consideration of this fact makes it evident that, if the manure produced from feeding the produce of the land be the only reliance for maintaining its fertility, there must inevitably follow, sooner or later, a deterioration in productiveness.

The systematic rotation of other crops with clover, and liming the land for the benefit of the clover, may postpone the day of reckoning, but it can only postpone it, for clover can add to the land only the one element, nitrogen, and every assistance to clover only facilities the removal of phosphorus; clover itself being a large consumer of this element.

These facts make it easy to understand why the first artificial fertilizers to come into general use should have been so predominately carriers of phosphorus as to give them the general name of "phosphates," and why such fertilizers should have been found equally effective in regions where dairying had been the prevailing industry, in those devoted chiefly to the production of grain, and in those in which the phosphorus had been extracted from the soil by corn and clover, to be combined with the abundant lime of such regions in the skeleton of the quick-growing hog.

The wide difference in composition, between farm manure and the artificial fertilizers that had been found most effective, suggested the question whether the effectiveness of manure might not be increased by reinforcing it with phosphorus and in 1897 an experiment was begun at the Ohio Experiment Station, in which it was hoped to obtain information upon the following points:

1. The effect on manure of reinforcing it with carriers of phosphorus or potassium.
2. The effect of treating manure with materials for the purpose of arresting the escape of ammonia gas.
3. The possibility of increasing the availability of raw phosphate by incorporating it with manure and other decaying organic matter.
4. The effect of exposure to the weather upon the value of manure.

In this test manure, usually produced by fattening cattle, is taken from the stable in January and divided into 5 equal parts, one of which is left without any treatment, while the others receive either raw phosphate rock, superphosphate, kainit, or gypsum, these materials being mixed with the manure at the arbitrary rate of 40 pounds per ton of manure. One half of each lot is then spread upon the clover sod in a three-year rotation of corn, wheat and clover, while the other half is left in a flat pile in the barnyard until April, when it is spread alongside the first half and both are plowed under for corn, the manure being applied at the rate of 8 tons per acre of the original manure. Wheat and clover follow the corn without any additional treatments.

Since 1905 all the land has had a basic dressing of ground limestone, applied at the rate of about 1½ ton per acre while the land was being prepared for corn. Each crop is grown every year and every third plot throughout the test is left without any manure or other treatment except the liming.

The outcome of this test for 30 years is arranged in Table XLVI in two periods of nine years each and a final period of 12 years, the first period showing the yields before liming was begun. The valuations are those hereinbefore employed, namely: 80 cents a bushel for corn with its stover, $1.25 a bushel for wheat with its straw and $12.00 a ton for hay.

The table shows the average annual unmanured yields

TABLE LXVI.—EFFECT OF REINFORCEMENT OF MANURE

PERIOD	*Plot No.*	*Manure and treatment*	*Unmanured Yield and increase*			*Gain from treatment*	
			Corn	*Wheat*	*Hay*	*Total*	*Excess*
			Bu.	*Bu.*	*Cwt.*	*Dol.*	*Dol.*
I		Unmanured yield	37.0	9.9	20.2	...	...
		Increase from manure—					
	15	Yard untreated . ..	14.7	8.2	7.0	8.74	...
	16	Fresh untreated	19.4	9.7	12.8	11.78	...
	2	Yard and raw phos.	19.8	13.4	16.1	14.10	5.36
	3	Fresh and raw phos.	25.4	15.5	25.4	18.30	6.52
	5	Yard and superphos.	24.4	14.9	17.9	16.29	7.55
	6	Fresh and superphos.	27.8	16.1	27.4	19.62	7.84
	8	Yard and kainit....	19.4	11.1	12.5	12.29	3.55
	9	Fresh and kainit....	23.5	12.8	20.5	15.70	3.92
	12	Yard and gypsum...	19.0	11.6	10.1	11.92	3.18
	13	Fresh and gypsum..	22.4	12.4	13.1	13.77	1.99
II		Unmanured yields....	34.7	13.8	30.4	...	...
		Increase from manure—					
	15	Yard, untreated	25.7	10.4	9.8	13.17	...
	16	Fresh, untreated ...	29.3	11.4	15.1	15.57	...
	2	Yard and raw phos.	31.3	10.9	15.6	16.00	2.83
	3	Fresh and raw phos.	38.5	12.9	20.1	19.67	4.10
	5	Yard and superphos.	39.3	15.3	20.7	21.00	7.83
	6	Fresh and superphos.	43.4	15.6	24.1	22.90	7.33
	8	Yard and kainit ...	30.1	10.0	11.3	14.45	1.28
	9	Fresh and kainit ...	33.9	11.3	16.5	17.07	1.30
	12	Yard and gypsum..	30.3	10.4	8.8	14.19	1.02
	13	Fresh and gypsum..	13.9	11.5	12.2	16.29	.72
III		Unmanured yields .	40.1	19.8	33.7	...	...
		Increase from manure—					
	15	Yard, untreated	23.8	9.1	8.9	11.91	...
	16	Fresh, untreated ...	26.3	9.6	11.2	13.24	...
	2	Yard and raw phos.	27.1	9.5	7.6	12.70	0.79
	3	Fresh and raw phos.	30.5	10.9	9.4	14.58	1.34
	5	Yard and superphos.	31.7	15.9	14.6	18.00	6.09
	6	Fresh and superphos.	30.3	16.0	16.5	19.06	6.42
	8	Yard and kainit ...	28.2	10.8	7.4	13.51	1.60
	9	Fresh and kainit ...	31.8	11.1	9.0	14.93	1.69
	12	Yard and gypsum..	27.2	8.3	7.2	12.15	0.24
	13	Fresh and gypsum..	28.8	8.8	8.2	13.00	—0.24

per acre for each period, the increase due to the untreated manures, and the excess over this increase due to the treatments.

Table LXVI shows that, except for a small reduction in the yield of corn during the second period, due to less favorable seasonal conditions, there has been an increase in yield of each of the crops on the untreated land from period to period, showing that the growing of clover every third season, with the help of lime, has thus far maintained the yield. Not only was there a considerable increase when liming was begun, but there was a further increase for the third period over the second.

The manures used in this test have been repeatedly analyzed by J. W. Ames and his coworkers, these analyses showing that the manure left in the barnyard had lost from 30 to 40 percent of its nitrogen, from 15 to 25 percent of its phosphorus and from 40 to 60 percent of its potassium, before being spread upon the field. These losses were relatively greater for nitrogen and potassium than for phosphorus because of the fact that the liquid excrement, which contains but little phosphorus, is the first to be leached out of the manure heap. The losses are greater in some seasons than in others, there having been occasional winters when the precipitation was so small that there was but little loss. Such seasons occurred more frequently during the later years, and account for the gradual gain in relative effectiveness of the yard manure.

Table LXVI shows that the loss in effectiveness of the yard manure has been measured by that of phosphorus, rather than by that of nitrogen or potassium, the average superiority in the increase of the untreated fresh manure over that of the yard manure being about 26 percent, 16 percent, and 15 percent of the former for the three periods respectively. Apparently, the combination of manure and clover is making good the nitrogen losses, and while clover does not add to the soil store of potassium it does bring up some of that element from the subsoil and leaves it in reach of the other crops.

During the first period, on unlimed land, the yields of hay were a little larger from the manure treated with raw phosphate than from the superphosphate treatment, but when liming was begun the raw phosphate dropped behind, and during the final period its increase was about half, with yard manure, and less than half, with fresh manure, of that from superphosphate, thus confirming again the conclusion that a part of the effect of raw phosphate is due to a small neutralizing effect on acid soil.

The increase from superphosphate has been somewhat smaller since liming was begun, an outcome partly explainable under the law of diminishing returns. Throughout the 30 years of the test, however, and with both manures, the increase from the equivalent of an annual dressing of less than 100 pounds per acre of 16 percent superphosphate has been several times the cost of the phosphate, and on the limed land the increase from superphosphate has been enough greater than that from the raw phosphate to justify its use, even though the raw phosphate had cost nothing.

Kainit apparently had about half as much effect on the unlimed land as superphosphate at first, but when liming was begun the effect of this carrier of potassium dropped practically to zero, its effect being smaller with the fresh than with the yard manure. Since the first period the effect of kainit has been shown chiefly or altogether in the corn crop.

The question may be raised whether the crops grown on the land receiving manure reinforced with phosphorus might not have been able to utilize more potassium. In another experiment, that has been running 14 years on land annexed to the Wooster farm, the yields for manure reinforced with both superphosphate and kainit have been smaller than those from manure and superphosphate only. Apparently, therefore, the supply of available potassium has been sufficient for the needs of the crop up to the present time.

The effect of gypsum was a little inferior to that of kainit during the first period, and has fallen to zero during the last. Gypsum, or "land plaster," is sulphate of lime, and is found in natural rocks, from which "Plaster of Paris" is made by burning, just as lime is made from common limestone. The unburnt rock, ground to powder, was used for land treatment long before superphosphate was used, and was believed to be especially beneficial to clover. The story is related that Benjamin Franklin once attracted attention to its effect by spreading it on a clover field so as to form the word "plaster."

Among the explanations of the effect of gypsum, the theory was advanced that it liberated potassium in the soil through the combination of its sulphur with the inert soil potassium, thus converting it into a more soluble form. Another theory was that it serves to conserve the ammonia of the manure heap by converting the escaping gas into the more stable sulphate. Kainit has been used for the same purpose, and under the theory, presumably, that it fixed the ammonia gas in the less evanescent salt, ammonium chloride or ammonium sulphate, kainit being a crude salt, containing sulphates and chlorides of potassium, sodium, magnesium and calcium.

Many laboratory tests had indicated that both gypsum and kainit, under certain conditions, had the effect of thus fixing ammonia. The problem which this experiment was designed to clarify was whether these laboratory results could be confirmed in field practice.

Superphosphate contains the same elements as gypsum, with the addition of phosphorus, and should be equally effective as a conserver of ammonia.

CONCLUSIONS

The experiments above considered show conclusively that farm manure, even when most carefully handled, fails to meet the requirements of a phosphorus-hungry soil, and that, after it has been used in liberal quantity, a further increase in yield beyond that produced by the manure may be gained by supplementing the manure with superphosphate.

It does not seem to be a matter of great importance whether the superphosphate be mixed with the manure, as has been done in these experiments, or whether it be applied separately to the land. What is of importance is that the superphosphate shall be used in such manner as to profit by the interaction between it and the nitrogen of the manure, and in many cases the most convenient method of application will be to use it daily in the stable, at the rate of about one pound per 1,000-pound animal per day, thus securing some arrest of ammonia and reducing, or at least not increasing, the labor of distribution.

These experiments afford no encouragement to the attempt to increase the availability of raw rock phosphate by incorporating it with manure, except for use on very acid soils, nor do they encourage the treatment of manure with kainit or gypsum for the purpose of arresting ammonia.

The comparisons of yard and fresh manure show that there may be very serious losses when manure is exposed to the weather. This problem was considered in the preceding chapter.

XXII

The Distribution of Fertilizers or Manure in Rotative Cropping

WHETHER to distribute a given quantity of fertilizer or manure between the different crops of a rotation or to concentrate the treatment for a rotation period on a single crop, and if so, on which crop, is a problem of practical interest to the farmer, for less labor is involved in making a single larger application than in several smaller ones.

Distribution of fertilizers—In the potatoes-wheat-clover rotation at Wooster and in the duplicate corn-wheat-clover rotations at Germantown and Carpenter a fertilizer made up of nitrate of soda, superphosphate and muriate of potash is divided on Plot 14 between the potatoes and wheat, giving the potatoes a little the larger share, or between the corn and wheat equally, while on Plot 15 the same total dressing is concentrated on the potatoes or corn. The wheat receives no further treatment in the potato rotations, the land having had a basic dressing of limestone, while in the other rotations the wheat receives 1,000 pounds of ground limestone. The average outcome, for 34 years at Wooster and 24 years at Germantown and Carpenter, is shown in Table LXVII.

TABLE LXVII.—DISTRIBUTION OF FERTILIZERS IN THREE-YEAR ROTATIONS

PLOT No.	*Station and distribution*	*Annual increase and value per acre*			
		Potatoes or Corn	*Wheat*	*Hay*	*Value*
		Bu.	*Bu.*	*Cwt.*	*Dol.*
14	Wooster: Potatoes and wheat......	49.8	12.3	8.4	20.00
15	Wooster: All on potatoes..........	48.8	10.6	8.3	19.00
14	Germantown: Corn and wheat.....	18.2	15.9	10.9	13.62
15	Germantown: All on corn.........	21.0	12.0	12.0	12.97
14	Carpenter: Corn and wheat.......	19.6	15.8	12.4	14.27
15	Carpenter: All on corn...........	21.4	12.5	16.2	14.17

The total dressing per acre in the potato rotation has consisted of 320 pounds nitrate of soda, 480 pounds superphosphate and 300 pounds muriate of potash, a total of 1,100 pounds for each 3-year period, of which the potatoes have received about two-thirds on Plot 14 and all on Plot 15. This treatment has raised the 34-year average yields on Plot 14 to 170 bushels of potatoes and 39.6 bushels of wheat per acre, which seems to have been near the limit of capacity for these crops in this climate. The yield of potatoes, it is true, would not be considered large in some sections, but at Wooster this crop has had to contend with disease for many years. The wheat yield, however, has not been exceeded by any authenticated yield for a similar period within the writer's knowledge.

When the moderate treatment given the wheat on Plot 14 has been transferred to the potatoes on Plot 15, already liberally fertilized, there has been a small reduction in the yield of wheat and no further increase in that of potatoes.

In the corn-wheat-clover rotations the total treatment for the 3-year period has consisted of 160 pounds of nitrate of soda, 480 pounds of superphosphate and 40 pounds of muriate of potash, or a total of 680 pounds for the period, a quantity which these crops have been able to utilize. The basic yields have been considerably greater over the western limestone than over the eastern sandstone, but the increases from identical treatments could hardly have agreed more closely had both tests been conducted in the same field.

Even in the potato rotation the advantage for the divided application has been small, while in the cereal rotations it has been still less. It would seem, therefore, that in such short rotations as these it is not a matter of much importance whether the fertilizer is given in one application or in two.

This problem is being further studied in the cereal rotations with the treatments shown in Table LXVIII.

In this experiment manure is used at the rate of five tons per acre on every corn crop on Plot 17 and on every wheat crop on Plot 21 (this plot is not repeated at Carpenter) and at the rate of ten tons per acre on alternate corn crops on Plot 18 and on alternate wheat corps on Plot 20. Lime, as hydrated lime at first and ground limestone later, is used at the rate of 1,000 pounds per acre as shown. This gives the equivalent of five tons of manure for every rotation, but when the lime is used only on alternate rotations the dressing per rotation is reduced to 500 pounds.

Table LXVIII.—Distribution of Manure and Lime in Three-year Cereal Rotations

Plot No.	Station Treatment and distribution	Annual increase and value per acre Corn Bu.	Wheat Bu.	Hay Cwt.	Value Dol.
17	Germantown: Manure, 5 tons on corn, lime on wheat	19.3	5.5	7.7	8.98
18	Germantown: Manure, 10 tons; lime, 1,000 lb. on corn, alternate rotation	16.7	6.8	6.6	8.60
20	Germantown: Manure, 10 tons; lime, 1,000 lb. on wheat, alternate rotation	12.2	8.1	7.4	8.11
21	Germantown: Manure, 5 tons on wheat; lime, 1,000 lb. on corn	12.3	9.5	11.7	9.60
17	Carpenter: Manure, 5 tons on corn, lime on wheat	17.8	10.4	11.1	11.32
18	Carpenter: Manure, 10 tons; lime, 1,000 lb. on corn, alternate rotation	18.8	9.5	10.0	11.00
20	Carpenter: Manure, 10 tons; lime, 1,000 lb. on wheat, alternate rotation	13.4	10.4	13.6	10.61

At Germantown the most effective treatment has been the manuring of every wheat crop and the liming of every corn crop. When both manure and lime are given alternately to the same crop it has been slightly better to give them to the corn than to the wheat. The outcome is complicated by the fact that in the alternate treatments the lime is reduced in quantity. If the differences in cost of liming were deducted the variations in annual value of increase would be smaller than those shown in the table.

A fourth study of this problem was begun at Wooster in 1915, in a four-year rotation of corn, oats, wheat and clover, grown on land receiving a basic dressing of limestone. In this test, 1,000 pounds of fertilizer having a 2-8-2 formula is distributed between the various crops of the rotation as shown in Table LXIX.

The fertilizer has had a slightly greater effect when concentrated on the three grain crops than when the clover was given a share (compare Plots 5 and 6). As between dividing the fertilizer equally between the corn, oats and wheat, or between the corn and wheat only, or giving it all to wheat, (compare Plots 6, 8 and 11) the differences have been too small, at the prices here employed, (corn 80 cents, oats 50 cents, wheat $1.25 per bu.; hay $12 per ton) to pay the difference in labor cost of application. Giving the fertilizer all to corn has been little better than giving it all to clover, which has been the least effective method of application.

TABLE LXIX.—DISTRIBUTION OF FERTILIZER IN FOUR-YEAR ROTATION. DISTRIBUTION, INCREASE AND VALUE PER ACRE PER ANNUM

	Distribution of fertilizer				*Annual increase per acre*				*Value of Increase*
PLOT	*On corn*	*On oats*	*On wheat*	*On clover*	*Corn*	*Oats*	*Wheat*	*Hay*	
No.	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Bu.*	*Bu.*	*Bu.*	*Cwt.*	*Dol.*
5	250	250	250	250	11.6	8.1	11.3	9.5	8.29
6	333	333	333	...	13.3	8.8	14.1	6.4	9.12
8	500	...	500	...	12.4	5.7	14.8	7.3	8.91
9	1,000	...	...	...	15.0	8.5	8.5	4.1	7.33
11	...	...	1,000	...	6.7	3.4	17.0	11.5	8.80
12	...	...	...	1,000	10.8	4.2	6.7	15.1	7.04
Average unfertilized yield					53.5	53.1	23.7	34.6	...

Apparently, the effect of the nitrogen of the fertilizer has been limited chiefly or wholly to the crop to which it was applied, leaving but little more than that of the minerals to be carried forward to the succeeding crops of the rotation, consequently the clover, having its own source of nitrogen, has wasted that given in the fertilizer.

Distribution of manure—In a continuation of this experiment, 8 tons per acre per rotation of shed manure has been distributed as shown in Table LXX, and has been supplemented with 480 pounds of superphosphate equally divided between the corn and wheat.

TABLE LXX.—DISTRIBUTION OF MANURE IN FOUR-YEAR ROTATION

		Increase and value per acre per annum				
PLOT	*Distribution of manure*	*Corn*	*Oats*	*Wheat*	*Hay*	*Value*
No.	*per acre per rotation*	*Bu.*	*Bu.*	*Bu.*	*Cwt.*	*Dol.*
32	4 tons on corn, 4 tons on wheat	19.0	7.9	11.7	10.9	10.09
33	8 tons, all on corn...........	22.2	9.2	10.5	8.1	10.09
35	8 tons, all on wheat..........	16.0	6.4	14.2	13.1	10.40
36	8 tons, all on new clover......	17.3	6.2	7.2	14.3	8.62

Distributing the phosphate as has been done in this test has so equalized the total effect that it has been practically immaterial whether the manure was given all to the corn, all to the wheat, or half to each crop. The slower action of the nitrogen of manure has also contributed to this result. With the manure, as with the chemicals, there has been a smaller effect when it was given to the young clover.

The manure is estimated to have carried 72 pounds nitrogen, 112 pounds phosphoric acid and 58 pounds potash per rotation, as against the 16.4 pounds nitrogen, 80 pounds phosphoric acid and 20 pounds potash carried in the 2-8-2 formula shown in Table LXIX, hence the larger increase shown by the manure.

The composition of the fertilizer—The experiment, some of the results of which are shown in Tables LXIX and LXX, also includes a study of the effect of different ratios between the nitrogen, phosphoric acid and potash in the fertilizer. The outcome of this part of the test is shown in Table LXXI.

TABLE LXXI.—COMPARISON OF DIFFERENT RATIOS IN THE FERTILIZER. INCREASE AND VALUE PER ACRE PER ANNUM

PLOT	*Formula*	*Increase*				*Annual Value*	*Cost of Fertilizer*	*Balance*
		Corn	*Oats*	*Wheat*	*Hay*			
No.	*Percent*	*Bu.*	*Bu.*	*Bu.*	*Cwt.*	*Dol.*	*Dol.*	*Dol.*
2	0-16-0[1]	8.9	3.7	9.4	7.1	6.24	3.00	3.24
3	0-12-4[1]	13.0	7.9	10.6	10.3	8.44	3.00	5.44
8	2- 8-2[2]	12.4	5.7	14.8	7.3	8.91	3.00	5.91
14	2-12-2[2]	15.6	9.1	16.4	11.2	11.06	4.00	7.06
15	4-12-2[2]	16.7	7.9	16.4	11.2	11.13	5.50	6.63
17	4- 8-4[2]	16.6	7.9	15.6	9.6	10.62	5.00	5.62
18	4- 8-8[2]	19.9	7.9	16.0	9.9	11.45	5.50	5.95

The fertilizers for this test are compounded of nitrate of soda, superphosphate and muriate of potash, mixed together as shown under the head of "home mixing of fertilizers" on following pages, and their cost is computed on the local retail prices of mixed fertilizers of similar analyses.

Table LXXI shows that superphosphate, when used alone, has given the smallest increase in the test, an outcome in harmony with the general experience that the full effect of either of the fertilizing elements is seldom attained when used alone.

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[1] 250 lbs. on every crop. [2] 500 lbs. each on corn and wheat.

On most soils the addition of potassium to superphosphate increases the effect. In this test the gain, both total and net, has been considerable, although the total number of units in the fertilizer has not been changed. Usually, however, the use of potassic salts in the absence of phosphorus results in small gain if not actual loss.

Previous to the World War the Germans were drawing upon the nitrate beds of Chile for half the nitrogen required by their farms, the other half being the ammonium sulphate produced from the coal used in their factories. Two-fifths of their phosphates came from the phosphate beds of the United States and Algeria, the other three-fifths from basic slag produced in their iron furnaces. All their potash came from their own mines, with enough to spare to supply the world in general. The war blockade cut off the external supplies of nitrogen and phosphorus. The nitrogen they made good by developing the recently discovered processes for extracting nitrogen from the atmosphere, but for the phosphorus there was no possible substitute. They tried to overcome its lack by nearly doubling the use of potassic salts, but their production of wheat and rye fell from 16,000,000 tons in 1913 to an average of 10,000,000 tons for the 3 years, 1916-1918, and that of potatoes from 52,000,000 tons to 30,000,000 tons.[3]

In the experiment under consideration the 0-12-4 combination of superphosphate and muriate of potash has been divided equally between the four crops of the rotation. When two of the potash units have been replaced by nitrogen and the phosphoric acid has been reduced to 8 percent, giving a 2-8-2 formula, and the treatment has been concentrated on Plot 8 on the corn and wheat, there has been a reduction in yields of corn, oats and hay, which has been compensated by an increase in the yield of wheat.

Comparing Plots 8 and 14 it appears that the restoration of the phosphoric acid to 12 percent has increased the yields of all the crops above those given by the 0-12-4 formula.

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[3] Statement by Louis Guichard, member of the French Chamber of Deputies, quoted in the *Living Age,* April, 1929, p. 114.

Increasing the nitrogen to 4 percent, on Plot 15, has added two bushels to the yield of corn, or less than half enough to pay for the nitrogen added, while the yield of oats has been reduced.

Reducing the phosphorus, on Plots 17 and 18, has been compensated for corn by increasing the potash, but not for wheat and hay.

As the test now stands, the 2-12-2 formula has given the most profitable yield, although not the largest, and it seems probable that a greater economy in treatment might have been secured by omitting the nitrogen altogether from the fertilizer for corn and using the 2-12-2 only on the wheat.

It must be remembered, however, that this land has received a basic dressing of ground limestone for every corn crop, which has favored the processes by which nitrogen is made available, both through nitrification and by the growth of clover.

Response of different crops to fertilizing—Tables LXIX and LXX show that in this test the wheat has given as many bushels of increase from the same quantity of fertilizer as corn, and that both wheat and corn have given larger increases than oats when all have had the same treatment, on Plots 2, 3, 5 and 6. Since the unfertilized, or basic yield of wheat has been less than half as many bushels per acre as those of corn and oats, it might seem that wheat is more responsive to treatment than other crops; but the problem is complicated by the fact that the corn in these tests is grown immediately after clover, while two other crops, corn and oats, intervene between the clover and the wheat.

The corn, therefore, has the advantage, not only of first access to the nitrogen provided by the clover, but also of the pre-digested mineral elements left in the clover residues. A more trustworthy comparison of the actual response of the three crops to treatment is given in the experiments in continuous culture, described in Chapter XV, since in these experiments the outcome is not complicated by residues of plant roots or of fertilizers left over by other crops than the one being treated.

Table LXXII shows the 35 years average basic yields obtained in these tests, the increases due to identical treatments, and the percentages which these increases constitute of the basic yields, arranged in two periods—the first 10 years and the last 15 years—the land being limed for corn and wheat during the last period.

TABLE LXXII.—COMPARATIVE RESPONSE TO FERTILIZING AND MANURING IN CROPS GROWN CONTINUOUSLY

TREATMENT ON EACH CROP PER ACRE PER ANNUM	*Basic yields and increase*					
	Bushels per acre			*Percent of basic yields*		
	Corn	*Wheat*	*Oats*	*Corn*	*Wheat*	*Oats*
	First 10 years, 1894-1903					
Basic yields	21..51	9.24	24.30	...	...	...
Increase						
Chemicals, 25 lb. nitrogen [4]	21.28	11.52	18.57	99	124	76
Chemicals, 50 lb. nitrogen [4]	29.05	13.67	23.44	135	148	96
Manure, 2½ tons	10.71	4.20	5.26	50	45	22
Manure, 5 tons	20.25	7.50	11.15	94	81	46
	Last 15 years, 1914-1928					
Basic yields	10.82	7.91	17.72	...	...	...
Increase						
Chemicals, 25 lb. nitrogen [4]	24.01	11.67	23.12	222	148	134
Chemicals, 50 lb. nitrogen [4]	30.24	15.18	32.36	279	192	188
Manure, 2½ tons	11.00	8.73	11.40	101	110	66
Manure, 5 tons	20.84	14.20	20.93	192	180	121

Table LXXII shows that wheat has responded more promptly than corn to treatment with chemicals and less so to that with manure; that corn has fallen off in yield more rapidly than wheat on untreated land, but that the tendency of the treatments has been to maintain the yields at near the original levels, and consequently that the relative gain for treatment has been greater for corn than for wheat during the final period. Oats has shown a greater ability to resist neglect, but has given a lower response to treatment than either corn or wheat throughout the entire test.

The inference that clover furnishes more nitrogen to corn than to wheat in such rotations as those under consideration, and the evidence of the evanescent effect of nitrogen, raise the question whether the rational system of fertilizing in such rotations would not be to depend altogether on clover to supply the corn with that element and to purchase it only for the wheat, as suggested above. Light is thrown on this problem by the 5-year rotation on the Wooster farm, in which Plot 8 receives the mineral fertilizers only, while Plot 11 receives the same minerals with the addition of 160 pounds of nitrate of soda each on corn, oats and wheat. The outcome has been that, in the 35 years average, the increase in corn and oats has been but little more than half the cost of the nitrate, while wheat has given a small profit. In the duplicate experiment at Strongsville no crop has paid for the nitrate, but the loss has been smaller with wheat than with corn or oats.

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[4] Together with superphosphate, 160 lb. and muriate of potash, 100 lb. on each crop and for both quantities of nitrogen.

Table XIX, Part IV, shows that, while there have been a few exceptions, the general rule has been that, in rotations in which corn has followed clover, adding nitrogen to the fertilizer has increased the yield of wheat by as many bushels as corn and hence by a much larger percentage, but this is evidently because of the place of wheat in the rotation, and not because of special responsiveness. (See Appendix.)

CONCLUSIONS

These experiments seem to warrant the following conclusions:

1. The immediate effect of the nitrogen of chemical fertilizers is expended chiefly in the crop receiving the application, and any further effect is mainly due to the nitrogen carried over in the increased growth of the roots and stubble of this crop.

2. The chief effect of the nitrogen furnished by clover is likewise found in the crop immediately following, but a larger residue is carried forward by the addition of the partially decayed clover residues to those of the crop following the clover.

3. A smaller relative proportion of the nitrogen in manure than of that in chemicals is available to the crop receiving the treatment and a larger proportion is carried forward in the combined organic residues of the crops and manure.

4. In rotations in which clover has been grown every third or fourth year it has made little difference whether chemical fertilizers have all been given to one crop in 3-year rotations, or manure all to one crop in 4-year rotations, or whether the same total treatment has been divided between the different crops.

5. Where clover has been repeated in the rotation every third or fourth year, and when the conditions have been made favorable to its growth by supplying phosphorus and potassium, and lime when needed, it has seldom been profitable to add nitrogenous fertilizers for the production of ordinary farm crops, at the present cost of fertilizer nitrogen. If any purchased nitrogen is used it should be applied in the light of the experiments reported in Chapter XIX.

6. There appears to be but little difference in the response of corn and wheat under like conditions to fertilizers carrying nitrogen.

XXIII

The Home-mixing of Fertilizers

THE chemical fertilizers, whose effect has been studied in the foregoing pages, have been compounded of a few simple materials, which are not only the most effective, but are usually the cheapest carriers of the essential elements. These materials may be purchased in any quantity, from a single sackful to carloads, through the Farm Bureau, if the local fertilizer dealer should decline to supply them. The mixing is as simple an operation as the mixing of the ingredients of a loaf of bread or a pudding, merely requiring the use of a barn floor or a wagon box instead of a dish pan; of shovels and hoes instead of spoons; of a sand sieve instead of a flour sifter; and of scales weighing pounds instead of ounces. There is absolutely no superiority in the fertilizer mixed at the factory over that mixed at home, provided the mixing is done with the same thoroughness that is required for making a loaf of bread, or for mixing sand and lime to make a mortar.

The one qualification to this statement is that it is not advisable for the farmer to attempt to make a superphosphate, because this, like the making of flour or sugar, does require special apparatus and some technical knowledge and skill; but superphosphate has become as distinctly an article of commerce, available wherever soil fertilizers are sold, as are flour and sugar.

The two points that should determine whether to use a factory-mixed or a home-mixed fertilizer are whether the factory mixture has been made of the best materials and whether it can be purchased as cheaply as a home mixture of the same composition, after making allowance for the small labor cost of home mixing.

Before the World War the prices asked for factory mixtures, especially those containing nitrogen, were usually much higher than the necessary cost of equivalent home mixtures, but since the war there has been a greater relative advance in the prices of superphosphate and potash salts than in those of nitrogen carriers and hence, as will be shown further on, it may sometimes be possible to purchase a factory mixture at a reasonable advance over the cost of an equivalent home mixture.

Materials for home mixing—Of the various materials that may be used in the compounding of a fertilizer the home mixer will usually select either nitrate of soda or sulphate of ammonia as the carrier of nitrogen; superphosphate, steamed bonemeal or basic slag as the carrier of phosphorus and muriate or sulphate of potash as the carrier of potassium.

Nitrate of soda should contain 15½ to 16 percent of nitrogen and sulphate of ammonia about 21 percent. As shown in Chapter XIX, nitrate of soda is effective for all soils and for all crops, while sulphate of ammonia should never be used on acid soils until they have been limed, except for potatoes and tobacco, for which crops it is slightly more effective than nitrate of soda. In 1927 the average wholesale price of nitrate of soda in New York was $49.90, and that of sulphate of ammonia $48.54 a ton. By the time these salts reach the average farmer in 100-pound sacks the price may reach $70 a ton, and the ammonia salt, notwithstanding its higher percentage of nitrogen, should not cost more per 100 pounds than the nitrate.

Because of the lower wholesale cost of the unit of nitrogen in sulphate of ammonia that material would naturally be selected as the chief source of nitrogen for factory-mixed fertilizers. The synthetic nitrogen products are also being reduced in cost, through improved methods of manufacture, and are being increasingly used in such fertilizers.

Superphosphate, heretofore known in America as acid phosphate, is the standard carrier of phosphorus for soil fertilization. It is produced by treating powdered raw phosphate rock with sulphuric acid, a process involving special apparatus and technical knowledge and skill. In some establishments the sulphuric acid is produced by burning iron pyrites, which is the combination of sulphur and iron found in the common rock known as "fool's gold," collecting the escaping gas in large lead chambers and causing it to combine with water by chemical processes; in others the great sulphur deposits of volcanic regions or of western Louisiana and Texas are used instead of pyrites for the production of this acid.

The better grades of phosphate rock contain around 28 percent of phosphoric acid, and in the earlier system of manufacture it was customary to mix rock of this grade with an equal weight of sulphuric acid of a certain strength, thus producing a 14-percent superphosphate, which was the standard grade for many years. With improvements in technique and the use of stronger acid the standard grade of superphosphate was raised to 16 percent, and during recent years the processes of manufacture have been so improved that superphosphate containing 18 to 20 percent or more may be purchased.

Usually, the pound of phosphoric acid may be bought for less money in the higher grades. For example, a 16-percent superphosphate is offered at $21.30 a ton and a 20-percent at $25.65, at which prices the 320 pounds of phosphoric acid in a ton of the 16-percent fertilizer would cost $6.66 per 100 pounds and the 400 pounds in the 20-percent grade would cost $6.41 per 100 pounds, a saving of 25 cents a hundred pounds, or a dollar per ton of phosphate, by purchasing the higher grade.

Muriate of potash (potassium chloride) is the standard carrier of fertilizer potash. It is a chemical combination of the elements potassium and chlorine, and is found in natural deposits, the most extensive of which now known are the mines near Stassfurt in southwestern Germany and across the Rhine in Alsace, France. Sulphate of potash is also found in the same region. Both the muriate and sulphate are associated with common salt (sodium chloride) and salts of magnesium in the crude salt, kainit. When separated and refined the commercial muriate and sulphate of potash contain about 50 percent actual potash. Kainit, containing 12 to 13 percent of potash, is used to some extent in its crude condition, but when freight is paid to America on its useless constituents its potash costs more per unit than that in the higher grade materials, notwithstanding its lower price per ton.

Equipment for home-mixing—The materials above mentioned are salts or powders. Nitrate of soda, like common salt, absorbs moisture readily and is apt to be somewhat lumpy, but the lumps are easily pulverized with the back of a shovel or a wooden pestle, and a mason's sand sieve or, for smaller jobs, a hand sieve, made by stapling a bottom of wire screen with a quarter-inch mesh to a frame made of 1″ x 6″ lumber, will be needed to sift out the lumps for this purpose.

The mixing may be done on a barn floor, either of plank or dry earth, or in a wagon box, the necessary tools being the same shovel and hoe that the mason uses in mixing sand and lime for mortar, though a revolving churn, such as is used in creameries, will be a convenience.

An example in home-mixing—Having these materials and equipment, let us mix a fertilizer having the formula 2-12-2: That is, one containing 2 percent nitrogen,[1] or 40 pounds per ton of fertilizer; 12 percent phosphoric acid, or 240 pounds per ton and 2 percent potash, or 40 pounds per ton. Computing nitrate of soda at 16 percent it will take 250 pounds to furnish the 40 pounds of nitrogen required by this formula. It will also require 1,500 pounds of 16 percent superphosphate and 80 pounds of 50 percent potash salt. The total requirement, therefore, will be 1,830 pounds, leaving 170 pounds to be "filled" with any convenient material —sifted dry earth or coal ashes, for example. But this filler will add nothing to the effectiveness of the fertilizer, and we may save labor and trouble by omitting it and reducing proportionately the dressing per acre.

The present Farm Bureau quotations for nitrate of soda and muriate of potash in carloads delivered to the locality where this is written are $64.15 and $54.35 per ton, respectively. Presumably retail prices would be about $3.50 and $3.00 per 100 pounds. Superphosphate is offered by local dealers at about $1.10 per 100 pounds. At these prices the cost of one ton of fertilizer would be as follows:

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[1] Previous to 1929 this constituent of the fertilizer was computed as "ammonia," which is about 82 percent nitrogen, but the National Fertilizer Association has decided to compute it as nitrogen hereafter.

250 lbs. nitrate of soda	$8.75
1500 lbs. superphosphate	16.50
80 lbs. muriate of potash	2.40
Total	27.65

Fertilizers of this formula are offered by local dealers at $29.90 a ton, thus showing a difference of $2.25 a ton to cover the cost of mixing.

TABLE LXXIII.—HOME-MIXED, VS. FACTORY-MIXED FERTILIZERS

No.	Formula	*Constituents per ton* *Nitrogen* *Lb.*	*Phosphoric acid* *Lb.*	*Potash* *Lb.*	*Nitrate soda* *Lb.*
1	0-14-4	..	280	80	...
2	1- 8-4	20	160	80	125
3	2-12-2	40	240	40	250
4	2-12-6	40	240	120	250
5	2-16-8	40	320	160	250
6	4-16-4	80	320	80	500
7	4-24-4	80	480	80	500

No.	*Materials required* *Super-phosphate* *Lb.*	*Muriate potash* *Lb.*	*Filler* *Lb.*	*Cost of materials* *Dol.*	*Price of factory mixture* *Dol.*
1	1,400	160	440	22.75	26.55
2	800	160	915	19.42	24.40
3	1,200	80	470	26.50	29.90
4	1,200	240	310	31.30	34.27
5	1,340 [2]	320	90	38.85	40.27
6	1,340 [2]	160	...	42.80	43.68
7	1,340 [3]	160	...	53.10	54.80

In Table LXXIII the composition of this formula is repeated, together with those of several others, using 20 percent, instead of 16 percent superphosphate except in the last three, for which a still higher grade is used to keep the total weight within the ton. It will be observed that the substitution of the higher grade superphosphate reduces the cost of the 2-12-2 mixture to $26.50 a ton, leaving a margin of $3.40 instead of $2.75, between its cost and the price of the equivalent factory mixture.

Attention is called to the last formula in this table, one ton of which contains the same total constituents found in 2 tons of the 2-12-2 formula, while the price of this one ton in the factory mixture is $5 less than that of two tons of 2-12-2, a difference accounted for in the saving of half the cost of freight and sacks.

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[2] 24 percent. [3] 30 percent

To compound this 4-24-4 formula and keep the weight within the ton a 30-percent superphosphate is indicated, but superphosphate of as high a grade as 44 percent is on the market, priced at retail at $56.00 a ton, or the equivalent of $6.37 per 100 pounds of phosphoric acid. Were this grade of superphosphate substituted for the 20, 24 and 30 percent grades assumed in Table LXXIII, the cost would be slightly reduced and the total amount of necessary material to be handled would be very decidedly reduced, as shown by Table LXXIV.

TABLE LXXIV.—MATERIALS NECESSARY FOR COMPOUNDING ONE TON OF FERTILIZER, USING 44 PERCENT SUPERPHOSPHATE

FORMULA	*Materials required* *Nitrate soda* *Lb.*	 *Super-phosphate* *Lb.*	 *Muriate potash* *Lb.*	*Total* *Lb.*	*Filler* *Lb.*
0-14-4	...	637	160	797	1,203
1- 8-4	125	364	160	649	1,351
2-12-2	250	546	80	876	1,124
2-12-6	250	546	240	1,036	964
2-16-8	250	728	320	1,298	702
4-16-4	500	728	160	1,388	612
4-24-4	500	1,090	160	1,750	250

This concentrated phosphate has not yet been sufficiently tested in the field to determine its relative value, but on theoretical grounds it would be expected, when properly used, to be at least as effective, pound for pound of phosphorus contained, as the best of the lower grades.

Returning to Table LXXIII, it will be seen that, as the amount of "filler" in the fertilizer diminishes so does the margin between the cost of materials and the price of the factory mixture, until in the higher analyses it becomes too small to justify home-mixing, except for the certainty of securing the most effective fertilizer for the purpose in view. Of one thing the farmer may rest assured, and that is that he can purchase no factory-mixed fertilizer of greater effectiveness than such a one as he can mix for himself out of the materials indicated in the table.

CONCLUSIONS

The refining of the crude nitrate and potassic salts; the combination of atmospheric nitrogen with oxygen; the production of sulphate of ammonia from coal and of sulphuric acid from pyrites or sulphur; the grinding of the raw phosphate rock and mixing it with this acid in proper proportion, these are definite manufacturing processes, involving special apparatus, technical knowledge and skill and large capital; but the mixing together of these manufactured products involves no more of such knowledge, skill and capital than is required for the intelligent combination of various feeding stuffs into a suitable ration for live stock feeding.

Whether one practices home-mixing or not, no one who uses fertilizers to any considerable extent can afford not to understand the principles involved.

XXIV

Green Manuring

By green manuring is meant the plowing under of crops grown for this purpose. The practice was probably first suggested by the improvement in tilth and in yield resulting from the plowing of sod land, the grass roots of which separate the particles of earth, making the soil more easy to cultivate, and furnishing as they decay a supply of predigested plant food to the crops which follow. When the entire crop is turned under, instead of only the roots and stubble, these effects are increased.

When leguminous crops are grown for this purpose there is, in addition to the effects above mentioned, an actual increase of the nitrogen store of the soil, through that obtained by these crops from the atmosphere.

Green manuring is expensive—To give an entire season to the growing of a crop to be turned under makes it an expensive process, and for this reason, and for the further reason that the crop so grown increases the demand for the mineral elements of fertility, this practice is followed to a very limited extent only. It merits, however, careful consideration as a method for the physical improvement of stiff clay or any soil which has been depleted of organic matter through improvident husbandry, and especially for conditions under which the use of manure is attended with difficulty or excessive cost, as on fields remote from the barnyard and on farms where live stock husbandry is not practised.

Value of nitrogen in clover—A ton of clover hay should contain 40 pounds of nitrogen, worth $10 or more at the price at which nitrogen is usually purchased in commercial fertilizers, or as much nitrogen as would be found in four tons of fairly good manure. In order to realize this value for the nitrogen in the clover hay it will be necessary to reinforce the hay with phosphorus, as a ton of hay carries only about four pounds of phosphorus, whereas the experiments described on previous pages have shown that for average soils the weight of phosphorus in the fertilizer should equal or exceed that of the nitrogen, if the latter is to be used with the greatest economy in rotative cropping. But it may sometimes happen that with such reinforcement it would be cheaper to plow under a crop of clover than to purchase the nitrogen necessary to produce a full crop of corn or wheat, taking into consideration the cost of harvesting and marketing the hay, and considering also the further fact that if the hay is sold off the farm it will carry away in each ton one or two dollars' worth of phosphorus and potassium in addition to its nitrogen.

Some crops grown for green manuring—When the common, or medium red clover is grown, the first, or June crop, is generally mown, and the second, or seed crop, is plowed under in case it has failed to produce a crop of seed. Some farmers grow the mammoth, or English clover, which produces seed in the first crop. When the heads have appeared the clover is rolled down; the heads then turn up and produce seed, which is harvested by clipping the heads and leaving most of the stems and foliage on the ground and this is plowed under.

Sweet clover, or melilot, is sometimes grown for this purpose, the entire crop being plowed under the second season. This plant is especially suited for rough and gullied lands where the use of harvesting machinery is impracticable, or where it is desired to introduce pasture grasses. Such lands may be sown to sweet clover and bluegrass at the same time, and after a few years the pasture grasses will occupy the land, the sweet clover having stored the soil with nitrogen and brought to the surface a supply of phosphorus and potassium. Alfalfa may be used in the same way and with the same result, but in the case of both sweet clover and alfalfa it is absolutely necessary that there be an abundance of lime in the soil. If not naturally there it must be supplied. A liberal supply of lime is also necessary to bluegrass.

Soybeans and cowpeas may be usefully employed as green manures, the cowpeas being extensively used for this purpose in the South. These being annual plants their growth is made in a single season. It is quite practicable to sow soybeans in May and have a good growth to turn under for wheat, at the end of August; but a still better plan would be to sow the beans in drills, cultivate through the summer and drill rye among them in September, both beans and rye to be plowed under early in the spring, for corn or potatoes. The frost of course kills the beans, but much of the nitrogen accumulated in their tissues will be held until spring, while the rye will gather and save the nitrates formed in the soil during the fall and spring.

Winter vetch, or a mixture of rye and vetch, would be better for this purpose than rye alone. The practical difficulty in the use of vetch is the high cost of its seed, but the two crops may be grown and harvested together, thus securing home grown seed. The rye supports the vetch, which is a trailing plant.

Catch crops—After corn or potatoes are harvested there is still some weather during the fall and early spring sufficiently warm for the formation of nitrates in the soil and, unless the land is occupied by a winter crop, there will be more or less loss of fertility through the washing out of the nitrates by rain. When corn or potatoes are followed with winter wheat this loss will be prevented, but it is sometimes difficult to get the cultivated crops off in time to get the wheat sown in proper season and the result is a diminished yield of wheat, due to late seeding.

Where it is not desirable to follow corn with wheat a so-called "catch crop" is sometimes sown in the corn in August. This may be rye alone, or better, rye and vetch, or rape, or cowhorn turnips, or, in southerly latitudes, crimson clover. In the South cowpeas are frequently sown in cotton for this purpose. The catch crop is plowed under in the spring.

A plan which would materially improve the texture of a soil that has been depleted of its organic matter, and where manure is not available, whether the soil be clay or sand, would be to sow to rye and vetch late in August, using a liberal quantity of seed and fertilizing with 300 pounds or more per acre of a mixture of about three parts superphosphate and one part muriate of potash, or equivalent materials, this crop to be plowed down in April and the field sown, after the middle of May, in soybeans or cowpeas, or a mixture of the two, these to be disked early in September and rye and vetch again sown, repeating the fertilizing. Such a treatment, continued through two winters and one summer, would start an improvement, which, if followed by judicious crop rotation and liberal use of the mineral fertilizers, would gradually bring the land into good condition.

When green manure may cause injury—The writer once sowed rye in corn at the end of August. A good growth was secured, and a dry November and April made it possible to pasture the rye with dairy cows during most of the late fall and early spring, the cows being kept off whenever the ground was sufficiently wet by rain to be injured by their trampling. The land was plowed early in April and was found so permeated with the roots of the rye as to be materially improved in tilth, and the second corn crop was better than the first. A few years later the same field was again in corn and was again sown in rye, which was allowed to grow until May before being plowed down. It was then heading out and it was necessary to turn it under with a chain. Corn was planted again as before, but dry weather followed, and the corn made only half a crop.

Similar results have been observed when a rank growth of clover has been turned under immediately before planting the land to corn or wheat. Instead of the expected improvement in the following crop it has sometimes been conspicuously injured, and it has been assumed that this injury was due to the souring of the land by acids produced in the decay of the green crop plowed under.

But the only acid which is produced in any considerable quantity in the decay of such matter as the crops which are turned under in green manuring is carbon dioxide, which would be given off as a gas and would be helpful, rather than injurious. The injury which has resulted in these cases has been due to the exhaustion of the water supply in the soil by the rank growth of the crop grown as a green manure, thus leaving an insufficient supply in the soil for the subsequent crops, and reducing the effectiveness of the supply by interposing a layer of fibrous material between the soil and the subsoil, thus interfering with the capillary action by which water is raised from the subsoil to supply the needs of crops in time of drought, where irrigation is not practised.

It should be remembered that the water which falls as rain during the summer months is very frequently insufficient to supply the needs of the crop without the aid of that which has accumulated during the winter and early spring, and if this accumulation has been pumped up and evaporated into the atmosphere from the foliage of a rank growth of rye or clover it is only to be expected that crops following these later in the season will suffer.

The green manure, therefore, should be turned under some weeks before the crop which follows it is to be planted, both to prevent this waste of water and to facilitate its transformation through decay into a form available to the crop which it is designed to nourish, and every precaution should be taken to conserve the water supply by immediate pulverization of the surface after plowing and by maintaining a moisture-conserving condition by harrowing after every rain.

XXV

Fertilizing the Orchard

Both orchard and pasture are conspicuous examples of continuous or single cropping. The life of the orchard should be half a century or more, and during that period, if it is protected from insect and fungous pests, it should remove the essential elements of fertility from the land in quantities that will compare with those carried in large yields of cereal crops.

For example, a 20-acre orchard has produced an annual yield of about 250 bushels of apples per acre for the twelve years since it came into bearing. Average analyses indicate that this quantity of apples would contain more nitrogen, phosphorus and potassium than would be contained in 30 bushels of wheat with its straw. In addition, the apple trees are storing very considerable quantities of these elements in their trunks and branches, which are also withdrawn from the soil, and even though the mineral elements carried in the foliage are returned to the land there will be a considerable loss of nitrogen through this source; and yet, on many farms, while the necessity for fertilizing the wheatfield is recognized, the orchard is supposed to be able to take care of itself.

A cow, giving two gallons of milk a day, will remove about 18 pounds of nitrogen, 10 pounds of phosphoric acid and 6 pounds of potash during six months pasturing, or as much phosphorus as would be carried in 15 bushels of wheat and its straw and somewhat less of the other elements. Growing cattle would appropriate nearly or quite the same quantities. When Ohio's pastures were new it was a common estimate that two acres should carry a cow through the summer, an estimate that would indicate a slower rate of soil exhaustion from pasturage than from cultivation, but the tens of thousands of acres of old pastures in Ohio on which broom sedge, daisies, golden rod and other weeds have so crowded out the pasture grasses that nearer six acres than two acres are now required per cow, are mute witnesses to the fact that pasture land is no more able to take care of itself than that devoted to cultivation.

When the orchard has had not only to furnish its crop of fruit but also to serve as a pasture, and when to this double duty has been added the loss of fertility from surface washing, the fact is not surprising that the apple crop, which was one that could be counted upon with the greatest assurance in the early history of Ohio, had become the least dependable one before the close of the State's first century.

Of course, insect and fungous pests had contributed a large share to the failure of the orchard, and were, in the popular mind, given exclusive credit for the mischief, but more careful study has shown that, both with orchards and pastures, the reduction of vitality of the trees and grasses through starvation has given the parasites and weeds their opportunity.

Difficulties in orchard experimentation—Experiments in fertilizing orchards have been undertaken by several experiment stations, but such work is much more difficult in the orchard than in the grain field.

The life of the apple tree is half a century, instead of a single season, and if the tree's necessities are to be fully understood it is as important to follow it throughout its entire cycle of growth as it is to follow the annual plant through its shorter period.

The tree manifests the same variation in individuality that is shown by other plants, and if we are to formulate any general law for the orchard we must deal with a sufficient number of trees to reduce the errors due to this factor to the minimum. A one-tenth acre—the most convenient size for an experiment plot—may contain 900 corn plants and several times that many plants of wheat, but a plot of this size would contain only four apple trees, if planted two rods apart.

In 1896 The New York Experiment Station attempted to reduce this source of error to the mimimum by planting Ben Davis trees, selected for uniformity, and topworking these trees to Rome, all the buds being taken from a single bearing tree, but with all this care, at the end of 15 years of bearing there had been variations as high as 30 to 40 percent both ways from the mean in the average yields of individual trees, grown on apparently uniform land and under the same treatment.

These trees were planted five to the plot on one-eighth acre plots, but with such a variation in yield no safe deductions can be drawn from the outcome, whereas if the same variation were distributed among 1,000 trees it would be negligible.

To conduct this work on a scale adequate to meet these difficulties would involve an outlay in men, money, time and land that no experiment station has as yet had the courage to undertake, nor would any State have provided the necessary support, and consequently the attempts at such investigation which thus far have been made have chiefly taken the form of cooperative work in leased orchards.

The results of this work have shown that, on land that is in fairly good condition, an orchard may be brought to the bearing age under cultivation without the use of any fertilizing material. If allowed to stand in sod, however, fertilizing or mulching will be necessary if satisfactory growth is attained.

After fruit production begins the time will come, sooner or later, when the foliage of the unfertilized orchard will become less abundant and lighter colored; when the fruit buds will suffer more from frost; insect depredations will be more difficult to control, and the fruit crop will be smaller and more uncertain. These changes will take place more rapidly if the orchard is left in sod than if cultivated, but cultivation without fertilization will only postpone the outcome.

In order to ascertain the effect of treatment it is necessary to leave untreated checks, and such checks have shown the owners of leased orchards the trend events were taking and have made them unwilling to have any part of the orchard left untreated, consequently it has not been practicable to continue experiments in leased orchards for a sufficient length of time fully to serve their purpose.

In view of the broader vision with which legislatures have looked upon scientific research during recent years and

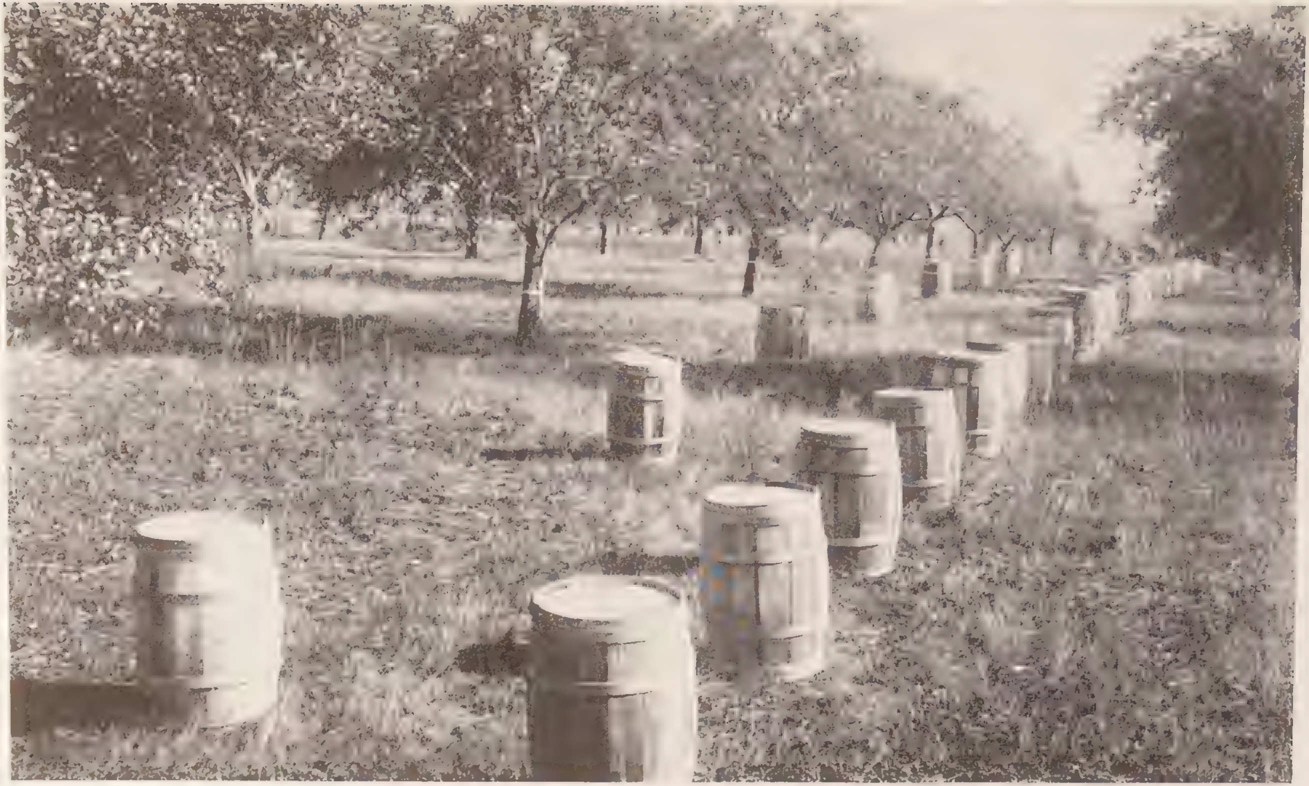

FIGURE XXIII.—EFFECT OF FERTILIZING ORCHARD

Production of 2 rows of Rome Beauty containing 8 trees each (1914). Row at right, fertilized for first time in April, 1914, yielded 21 barrels; row at left, unfertilized, 9 barrels. Photo by F. H. Ballou.

the greater experience gained in the conduct of such research, it is to be hoped that the time is not far distant when the problems of the orchard shall be attacked on a scale commensurate with their importance.

Effect of fertilizing Ohio orchards—One of the earliest settlements of the white man in Ohio was made at Marietta by emigrants from New England, one of whose first activities was the revival of their homeland traditions by the planting of extensive orchards on the hillsides of their new home. On this new soil and under a favoring climate the orchards throve. The rivers offered convenient and cheap transportation; the cities that were growing up in the South were hungry for fruit, and the production of apples to be transported by flatboat to the southern markets became a large and profitable industry.

But apple trees, like men, grow old, and the natural decrepitude of advancing years was aggravated in the case of these orchards by starvation, thus inviting attack by parasitic pests, and when the old orchards were replaced by new plantations, made often upon the old sites or upon land that had been impoverished by many years of exhaustive husbandry, the young trees found a host of enemies waiting for them and found the supply of plant food insufficient for the production of a vigorous growth. The consequence was that the annual production of apples in Washington County fell from an average of nearly a third of a million bushels for the 20 years, 1870-1889, to 91,000 bushels for the first decade of the new century.

In 1909 the Ohio Experiment Station leased several orchards in this section and began experiments which included both spraying for parasite control and fertilizing the land. The results were immediate and decisive. Either spraying alone or fertilizing alone had comparatively little effect, but when the two were combined the outcome was marvelous. Trees, which previously had lost a large part of their foliage before the end of summer and which had produced a few scabby apples, now held their leaves to the end of the season and were loaded with fine, smooth fruit; and orchards that had been condemned to the axe became the chief source of income for the farms on which they were located.

The results of this work are reported in detail by F. H. Ballou, of the Horticultural Department of the Ohio Experiment Station, under whose immediate supervision the work was conducted, in Bulletins 301 and 339 of that Station.

From what has thus far been done in orchard fertilization the following conclusions are drawn:

1. **Orchard spraying is indispensable**—The fungous and insect pests of the orchard have obtained such a foothold, practically everywhere, that the fight against them must be constantly maintained. As this is a separate problem from the one under discussion in this volume it will not be considered in detail here.

2. **Orchard cultivation**—The cultivation of the orchard has for its principal object the preservation of moisture, and in arid climates may be justified for this purpose. As a method for permanently maintaining fertility, however, cultivation alone cannot be recommended, for its result is to make the organic reserves of the soil more rapidly available and hence it leads to earlier exhaustion unless the cultivation be accompanied by fertilization. Further disadvantages of cultivation are the labor involved, the inconvenience of working over the plowed and sometimes muddy ground to harvest the crop in humid climates, and more than all else, the loss due to washing, if the orchard is located on sloping land, which is usually its most desirable situation.

3. **Orchard mulching**—As a preservative of moisture mulching is far more effective than cultivation, and its cost may be offset, in part at least, against that of cultivation. What is known as the grass-mulch system is of general application in humid regions, and possesses several advantages. In this system the land is kept permanently in grass, which is mown twice each season and spread under the trees, with the addition of other mulching material when practicable. Under this system nothing is taken out of the orchard except the fruit, while the land is always in the best condition for the use of spraying machinery, for harvesting the fruit and for resisting erosion. The objections to this system are the danger from fire and the possibility of harboring mice and insects in the mulching material. Because of these risks some prefer leaving the grass where it falls without spread-

ing it under the trees and making a little larger expenditure for fertilizers.

A modification of this practice is to head the trees very low and spray and fertilize liberally. In an orchard that has been managed after this plan for 25 years the luxuriant foliage has so completely shaded the ground that but little grass grows under the trees, evaporation is reduced almost as much as it would be by a mulch, and more than half of the abundant crops of apples are picked without the use of a ladder.

4. **Orchard fertilizing**—Whatever method of management is adopted, the fertility of the land must be maintained if the best results are secured, and the outcome of the work thus far done in the fertilizing of orchards is in harmony with the general principles of fertilization indicated by the experiments described in preceding chapters, and which may be restated in their application to the orchard as follows:

(a) The orchard must obtain from some source supplies of nitrogen and mineral elements to replace those removed from the land in its growth and produce.[1]

(b) Unless **nitrogen** can be found in the soil or obtained from the atmosphere by the growing of nitrogen purveying crops it must be provided from other sources, and as the space for such crops becomes reduced by the spread of the trees, and at the same time the draft of the trees on the land becomes greater, the demand for nitrogen will be constantly more urgent and the soil store of that element, however liberal it may have been at the outset, will eventually become depleted.

(c) **Phosphorus** is not less essential than nitrogen to all vegetable and animal growth. The orchard may require proportionately less of this element than do the cereal crops, but the quantity that is required is indispensable and without it much of the nitrogen that might be utilized will be wasted. If the land occupied by the orchard has been cropped or pastured for a considerable period its phosphorus reserves are certain to be low.

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[1] The fact is not overlooked that in practically all soils there are processes at work by which some of the plant food stored in the basic rocks is gradually made available from season to season, so that the land never becomes absolutely barren. On the other hand, experience has shown that we can not feed our crops, as we do our animals, in the assurance that the platter will be licked clean, for the theoretical availability of the fertilizing materials at present in use is practically never attained, and we must give more than we expect to recover.

(d) **Potassium** is also indispensable, but trees with their deeper rooting habit, and possibly with a greater capacity for utilizing crude combinations of this element than are available to other crops, may be able to obtain their supply of it with comparatively little assistance. The high content of wood ashes in potassium was at one time supposed to indicate the necessity for potash fertilization in the orchard, but we now interpret it as evidence of the tree's ability to obtain potash from sources unavailable to other plants.

(e) **Lime**—With its great root range the apple tree is relatively indifferent to the lime supply, but as an indirect purveyor of nitrogen lime may have great value in the orchard, for only where the supply of lime is abundant can the clovers perform their function.

Numerous tests have shown that young trees will grow much more rapidly under cultivation than if left in sod without mulching or fertilizing, for under such conditions the grass robs the tree of both moisture and plant food, but this is an alternative that should not be contemplated. An ideal system, where the soil and its topography permit, would seem to be to cultivate the orchard until it comes into bearing and then to seed it to alfalfa, this to be mown and spread under the trees for mulch. Cultivation, however, cannot be continuously practised on land subject to washing, nor can alfalfa be grown successfully on land deficient in lime. Where such a system as that suggested can be followed the purchase of nitrogen may be deferred for a considerable period, but under any system the time will eventually arrive when the trees will require more nitrogen than can be obtained in this way.

High value of crop justifies larger expenditure for fertilizer—Farm manure is a useful fertilizer for the orchard when available, because of its high content in nitrogen, but where manure is not available nitrogen may be purchased for the orchard with greater assurance of profit than is the case with crops of lower acre value. This is illustrated by Table LXXVI, which shows the difference a higher price per bushel would make in the financial outcome of the continuously grown wheat at Rothamsted and Wooster.

TABLE LXXVI.—EFFECT OF HIGH VALUE OF PRODUCE ON PROFIT FROM FERTILIZING

		Value of increase		*Cost of*	*Balance*	
	Nitrogen	*At $1.00*	*At $2.00*	*nitrogen*	*At $1.00*	*At $2.00*
STATION	*Lb.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*
Rothamsted[2]	43	10.30	20.60	9.46	0.84	11.14
	86	19.30	38.60	18.92	0.38	19.68
	129	23.50	47.00	28.38	—4.88	18.62
Wooster	25	11.60	23.20	5.50	6.10	17.10
	50	14.90	29.80	11.00	3.90	18.80

The table shows that, while the larger doses of nitrogen were given at a relative loss with wheat at $1, they would be more profitable than the smaller doses with wheat at $2, except for the largest dressing at Rothamsted, but with wheat at $3 even this treatment would be much more profitable than any smaller one. When we compare wheat, with its potential acre-yield of 40 bushels, with apples, with a potential acre-yield of 400 bushels this point becomes still more impressive.

Maintaining the nitrogen supply—In fertilizing the sod orchard it is desirable so to treat the land unoccupied by the trees as to encourage the growth of clover in order to get all the help possible from clover in supplying the trees with nitrogen, and to this end the interspaces should receive fertilizers carrying phosphorus and potassium, with lime added on soils deficient in lime. The trees, however, need nitrogen in addition to these minerals.

An average annual yield of 250 bushels of apples per acre would mean that twice this quantity should be obtained in the more favorable seasons, and such yields have frequently been reached. Such a yield would contain about 25 pounds of nitrogen in the fruit, while the foliage and tree-growth would probably contain as much more. For an indefinite period the soil will furnish a part of the nitrogen required, but in decreasing amounts, and some nitrogen will be brought down in the annual rainfall, but it cannot be expected that these sources will supply the demands of the increasing yields made possible by the growth of the trees, nor that all the nitrogen applied in fertilizers will be found by the tree-roots, and since only a very small fraction of the nitrogen made available during any season will be carried over to the next, the annual treatment should be sufficient to provide for the maximum crop.

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[2] See Table XXXII.

Methods of fertilizing the orchard—Short-time experiments, made by the Pennsylvania and Ohio experiment stations, indicate that a given amount of nitrogenous fertilizer will produce a greater immediate effect on the trees if spread in a belt around the outer margin of the branches than if applied to the entire area, and as clover, which should be encouraged to occupy the interspaces, requires only the mineral fertilizers, the practice is advocated of applying these as a basic dressing to the entire area and limiting the costly nitrogen carrier to the territory in which the tree-roots are feeding.

Twenty-five pounds of nitrogen would be carried in 160 pounds of nitrate of soda or 120 pounds of sulphate of ammonia, either of which would be a moderate dressing if spread over an entire acre; but in actual practice the trees in a 25-year old orchard are occupying about one-fourth of the entire area, and the belt to which the nitrogen salt is applied is not more than half the space occupied by the tree, hence the dosage at these rates of application would be equivalent to about 1,300 pounds nitrate of soda or 1,000 pounds sulphate of ammonia per acre, if spread over the entire area—rates far beyond the most toxic rate of sulphate of ammonia used in the Pennsylvania test, described in Chapter XIX.

The fact that the apple tree is apparently indifferent to ordinary soil acidity would justify the expectation that any injurious effect from sulphate of ammonia would be later in making its appearance in the orchard than with field crops, but the help that the clovers can give in maintaining the nitrogen supply would justify an occasional liming for that purpose alone, aside from the insurance that the liming would give against any possible injury from the ammonium salt.

XXVI

Fertilizing the Pasture

No part of the average farm has suffered more from neglect than the pasture. Year after year its produce has been consumed, and the only restitution made has been the droppings, which have concentrated the restitution on little spots in the case of the larger animals, and on the higher ground occupied at night by the sheep. In addition to this depletion, on many farms cattle have been permitted to range over the pastures in early spring while the ground was soft, and their trampling has not only injured the texture of the soil, but has planted the seeds of weeds, and where two acres of pasture were sufficient to carry a thousand-pound animal through the summer when the pastures were new, four to six acres are now required, while daisies, cinquefoil, golden rod, yarrow, broomsedge and plantain shout in triumph over the destruction of their enemies, the grains and clovers.

Elements removed in pasturing—The first removal from pastured land of the elements of fertility is that of the constituents of bone, lime and phosphorus. Whether the pasturage be by growing animals or by those giving milk, the materials for bone formation will be removed. Nitrogen also is consumed in growth, whether of bone or other animal tissues, but for a long time the loss of nitrogen from pastured land can be made good by the growth of clover.

Changes in herbage of land continuously in grass—Eventually, however, and this will happen sooner over sandstone than over limestone, the clovers will find too little lime to support their growth, and will be replaced by weeds and acid-tolerating grasses, and there will be a serious reduction in the feeding value of the pasture.

Table LVI (page 217) shows that in the Rothamsted Park, which was an old pasture at the beginning of the test,

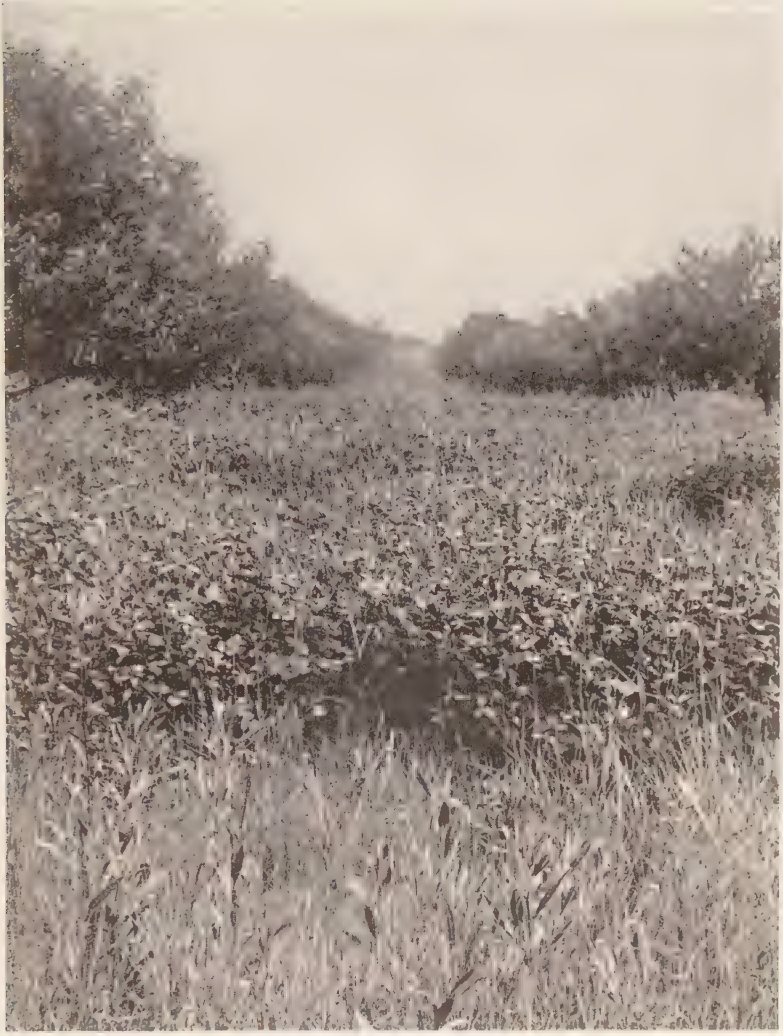

FIGURE XXIV.—EFFECT OF FERTILIZERS ON NATURAL HERBAGE

The orchard had never been fertilized and had not been cultivated for a number of years. It was covered with the sparse growth of weeds and inferior grasses shown in the foreground. An application to the surface of phosphorus and potassium, in superphosphate and muriate of potash, produced the rank growth of clover shown in the middle ground *without any reseeding*. Careful examination revealed small, starved plants on the unfertilized land, only needing to be fed to enable them to overreach and smother the weeds. Photo by F. H. Ballou.

the plants included in the other orders than gramineae and leguminoseae had reached an average of nearly one-third of the entire herbage by the end of the 61-year period. The detailed records of the work show that at the beginning of the test this proportion was about one-fifth, and that during recent years it has frequently been one-half of the whole.

Pasture experiment at Cockle Park, England—The Northumberland County Experiment Station is located at Cockle Park, in the northeast corner of England. The Station was established in 1897, and for a number of years, until his death in 1927, was conducted under the direction of Douglas A. Gilchrist, M. Sc., Professor of Agriculture in Armstrong College, Newcastle-upon-Tyne.

The soil of this farm is a somewhat heavy clay loam, lying over sandstone. An experiment in the treatment of pasture land has been in progress here since the establishment of the Station, in which the effect of treatment is measured by the increase in live-weight of pastured animals. In one section of this test the plots, about three acres in size, are enclosed by wire fence, and enough sheep are kept on each plot to consume the grass.

In Table LXXVII some of the results of this experiment are shown for the 6-year period, 1918-1923, stated in terms of American weights and values, the value of the increase in live weight being computed at 7 cents a pound, the approximate average rate on American farms during recent years, as computed by the United States Department of Agriculture.

Table LXXVII shows that it has been better to give the treatment all at the beginning of the 6-year period than to divide it (compare Plots 3 and 4); that basic slag has been a little more effective than superphosphate (compare Plots 4 and 5) and that neither nitrogen, potash nor lime has profitably increased the yield over that produced by basic slag alone, as measured in feeding value of the herbage, the lime carried by the basic slag having been sufficient on this soil so to increase the growth of white clover that it has maintained the nitrogen supply, while the soil store of potash has apparently been sufficient here for pasture requirements.

When larger fields were employed and were grazed with

TABLE LXXVII.—TREATMENT OF PASTURES AT COCKLE PARK. TOTAL TREATMENT AND INCREASE PER ACRE FOR SIX-YEAR PERIOD

PLOT No.	Treatment	Cost of treatment Dol.	Total increase Lb.	Value of increase Dol.	Net gain Dol.
3	Basic slag 1,120 lb. 1918 (200 lb. phos. acid)	14.00	519	36.33	22.33
4	Basic slag 560 lb. 1918, repeated 1921	14.00	444	31.08	17.08
5	Superphosphate (100 lb. phos. acid) 1918, repeated 1921	14.00	435	30.45	16.45
7	Basic slag as on 4: muriate potash, 100 lb.1918 and 1921	19.00	408	28.56	9.56
8	Basic slag as on 4: 1 ton lime 1918 and 1921	24.00	388	27.16	3.16
9	Basic slag as on 4: nitrate soda 112 lb. 1918 and 1921	21.80	300	21.00	—0.80

TABLE. LXXVIII.—FERTILIZING MEADOW AT COCKLE PARK. TWENTY-SEVEN-YEAR AVERAGE TREATMENT, YIELD AND VALUE PER ACRE PER ANNUM[1]

PLOT		Cost of treatment	Yield of hay	Total value	Net value	
					In the meadow	In animal increase
No.	Treatment	Dol.	Lb.	Dol.	Dol.	Dol.
6	None	...	2,114	12.68	12.68	21.14
8	Basic slag: 300 lb.	3.30	2,828	16.97	13.67	29.57
7	Sulphate of ammonia, 150 lb.	4.50	2,576	15.45	10.95	18.68
10	Basic slag, 300 lb., Sulphate ammonia, 150 lb.	7.80	3,332	20.00	12.20	27.18
12	Basic slag, 300 lb., muriate potash, 100 lb.	5.80	2,856	17.14	11.34	30.57
13	Basic slag 300 lb., muriate potash, 100 lb. sulphate ammonia, 150 lb.	10.30	2,444	20.66	10.36	28.10
2	Farm manure, 9 tons	16.90	4,452	26.71	9.81	34.07

[1] Tables LXXVII and LXXVIII are computed from Bulletin 36, 1924, published by Director of Education, The Moothall, Newcastle-upon-Tyne, England.

both sheep and cattle the grass was more completely utilized, one class of stock consuming what the other left, and the total gain was considerably greater.

The writer had the privilege of inspecting this pasture experiment in 1920, and found the growth on the slag-treated plots consisting of a dense mat of white clover and bluegrass, while that on the untreated land was a thin stand of bent grass of little nutritive value.

FIGURE.—XXV.—HOW TO GROW BROOMSEDGE

Division line between fertilized and unfertilized Rome Beauty plots at the close of the second season's work (1915). In the fertilized plot at the right is a dense mass of white clover mixed with bluegrass, redtop and some timothy. The unfertilized plot at the left remains thinly covered with mixed native weeds and poverty grass; also many young plants of broomsedge are showing. No seeding. Photo by F. H. Ballou.

Effect of nitrogen on herbage of grass land—The addition of nitrogen to the fertilizer has increased the proportion of the grasses in the herbage at the expense of the clover, and thus, while the total weight of produce may be greater, its feeding value is reduced.

This point is brought out by another experiment on the same farm, in which hays, produced by different fertilizer treatments, have been fed and the relative value has been computed on the outcome of the feeding tests. Some of the results of this experiment are shown in Table LXXVIII, which gives the different treatments and their cost, computing basic slag at $1.10, sulphate of ammonia at $3 and muriate of potash at $2.50 per hundred pounds, together with the average annual yield of hay for 27 years and the value of this yield, computed at $12 a ton in the meadow and as found after feeding it to livestock in controlled experiments. This latter valuation is based upon English prices for increase in live weight and is higher than might be realized under American conditions, but this point does not affect the relative comparisons.

Table LXXVIII shows that, while the addition of nitrogen to the fertilizer has increased the yield of hay, the increase has never been sufficient to pay for the nitrogen, with hay at $12 a ton, whereas the basic slag has given a small profit. When measured by feeding value the slag-fertilized hay has been materially increased in value, as compared with that grown on unfertilized land, and the hay fertilized with slag alone, or with slag and muriate of potash, has given a larger net increase per acre than that grown with nitrogenous fertilizers.

The explanation of this outcome lies in the fact that the effect of the combination of phosphorus and lime in basic slag is to encourage the relative growth of clover, and thus to increase the proportion of protein in the herbage and with it the feeding value of the hay, whereas the nitrogenous fertilizer increases the non-leguminous herbage at the expense of the clover (see Table LVI) and while the proportion of protein in the non-legumes is probably increased the total protein per acre, and with it the total feeding value, is reduced.

In other words, the growth of clover, stimulated by the combined lime-phosphorus treatment, has been a cheaper source of protein than nitrogenous fertilizers.

Manuring grass lands—Farm manure, as used in this test, has given a larger total yield than any other treatment, and when reckoned in feeding value the net gain has been greater, but this has been in part because the elements of fertility have been given in larger quantity in manure than in the chemical fertilizers, and in part, apparently, because the organic nitrogen of manure is less inhospitable to the legumes than the nitrogen of the ammonium salt.

The eight English, equivalent to nine American tons of manure used here have probably carried approximately the same quantity of phosphorus as the 300 pounds of basic slag and considerably more nitrogen and potash than were given in the chemicals.

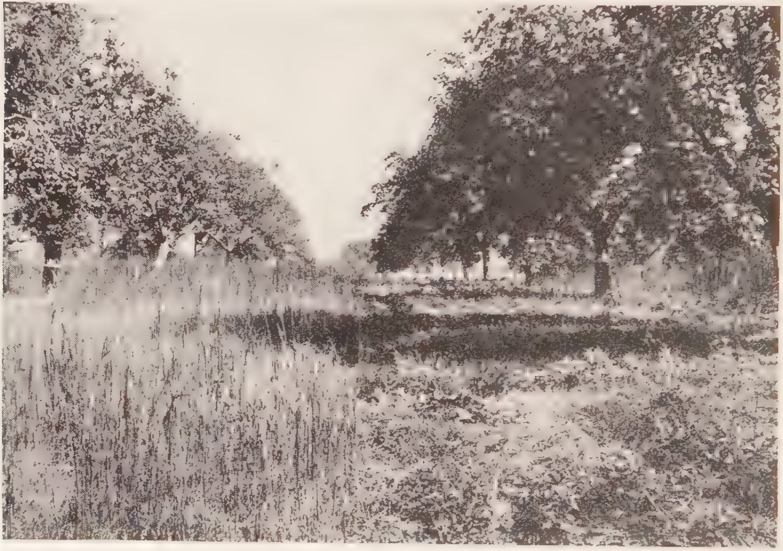

FIGURE XXVI.—HOW TO GROW BROOMSEDGE

Same plots as shown in Figure XXV, one year later. Broomsedge has densely invaded the unfertilized plot, but has not crossed over the plot boundary line into the fertilized plot which is now thickly matted with white clover and an aftermath of mixed grasses. These two plots had been clipped with the mowing machine the same day in June. Photo by F. H. Ballou.

Effect of fertilizing pastures on weeds—Observation tests, made on the hill pastures of the Southeastern Testfarm of the Ohio Experiment Station 20 years ago, were so convincing that the policy was adopted then of giving alternate dressings of limestone and superphosphate, two years apart, with the outcome that the daisies, cinquefoil and yarrow that had taken possession under many years of cattle

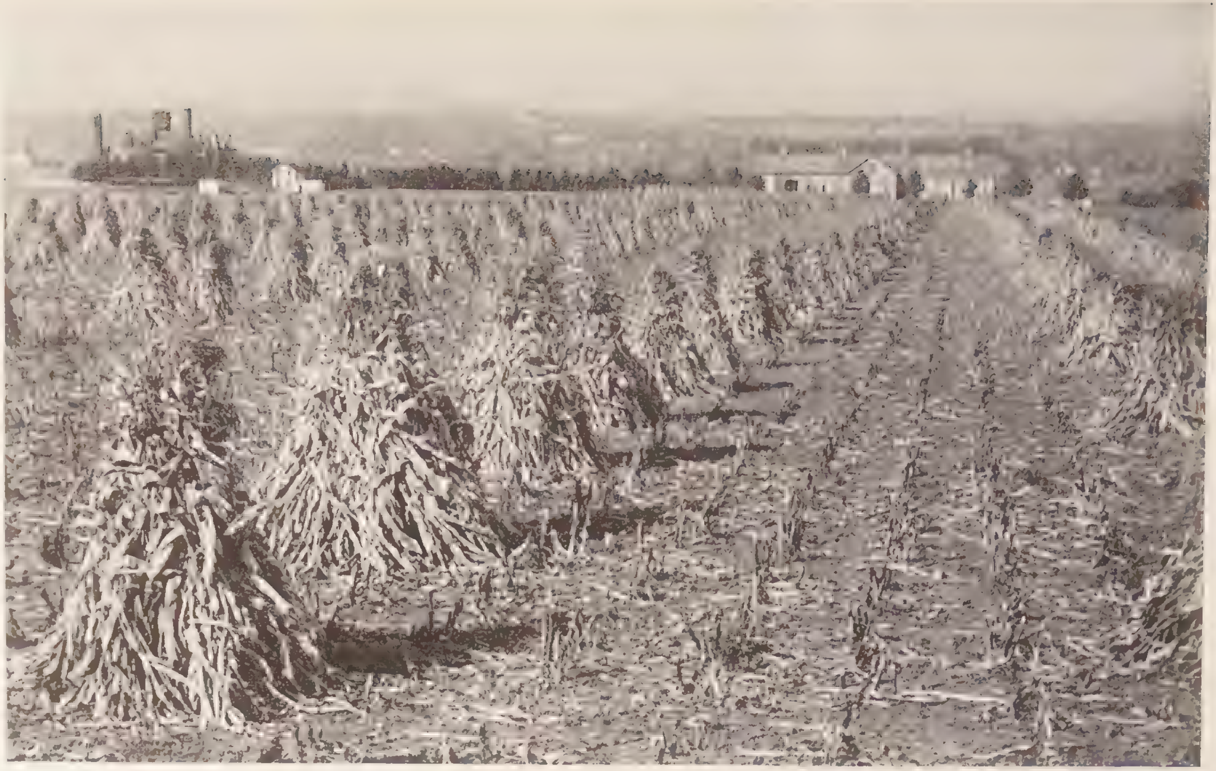

FIGURE XXVII.—CORN IN FIELD CULTURE, OHIO EXPERIMENT STATION

One of the four 10-acre fields at the Ohio Experiment Station which have averaged 76 bushels of shelled corn per acre for 23 years. This crop (1915) made 78 bushels. Rotation with clover; powdered limestone and phosphated manure on corn, fertilizer on wheat; carefully selected seed; full stand and shallow cultivation, have been some of the factors contributing to this outcome on a thin, light clay soil that, with equal care and labor, but without manure, lime or fertilizer, has averaged but 50 bushels during the same period. Photo by E. J. Houser.

pasturage have largely disappeared under the sheep's foot, and have been replaced with grasses and white clover. Attention is called to Figures XXV and XXVI, showing the effect on broomsedge of fertilizing a southern Ohio pastured orchard.

In these tests it was found advisable to reseed the land in order to get an earlier stand of the better grasses and white clover than could be secured by depending upon volunteer seeding. To this end the land was scarified and the seed covered in by disk harrowing.

The Journal of the American Society of Agronomy for June, 1929, is a symposium on "Pasture Management Research," containing papers showing that a considerable number of American experiment stations have begun systematic investigations on this problem from which valuable results may be anticipated. Among the interesting points brought out in this symposium is that results thus far attained indicate that, under intelligent management, the pasture may show quite as large a production of feed units per acre as that obtained in crop rotation, and at a considerably lower cost per unit.

CONCLUSIONS

The immediate effect of using on grass fertilizers carrying soluble nitrogen compounds is to darken the foliage and give the plant a thriftier appearance, but experienced farmers have learned that it is not always the rankest growth that is the most nutritious, and the experiments here considered have confirmed this experience by showing that, while the increase of protein in the acre's yield, indicated by the darker color of the grass, is important, it is still more important that the protein be fully supported by the mineral elements that constitute the basis of the skeleton. It follows, therefore, that the application to the pasture of nitrogen-carrying salts will give disappointing results unless these salts are accompanied by the bone-forming elements, and when this is done the clovers will take care of the greater part of the protein supply.

It is true that deficiency of the feed in these elements may be in some measure overcome by the addition of mineral supplements to the ration, but no supplement has yet been found to be so safe and effective as bluegrass-white clover pasturage, a combination that can only be secured on land well supplied with lime and phosphorus.

XXVII

Fertilizing Truck Crops

In 1914 the Ohio Experiment Station, in cooperation with Washington County, established a truck experiment farm on the terrace of the Muskingum Valley, a few miles north of Marietta, as a division of the county experiment farm, the field crop and orchard section of which was located at Fleming, on upland in the western part of the county.

Early cabbage, tomatoes, cucumbers and sweet corn are grown on this truck farm in a 4-year rotation, each crop being grown every season. No clover is included in the rotation, but soybeans are sown after the cabbage is harvested and among the tomatoes and corn at the last cultivation, excepting on part of the land that receives manure. The soybeans are disked in before frost and rye is sown as a winter cover crop over the entire area, including the land that has been in cucumbers.

On part of the land yard manure is used at the rate of 16 tons per acre on each crop. Because of difficulty in getting a sufficient supply of manure at Marietta it has been shipped in from the military post at Chillicothe, thus increasing the cost to $3.75 a ton, delivered at the truck farm, a cost that makes it a more expensive fertilizer, pound for pound of essential elements contained, than one of equivalent composition compounded of nitrate of soda, superphosphate and muriate of potash.

Composition of treatments in truck experiments— These chemicals have been used on part of the land, both separately from manure and as a reinforcement of manure, but unfortunately the chemicals have not been so used as to duplicate the composition of manure, as shown by Table LXXIX, which gives the estimated composition of certain selected treatments.

TABLE LXXIX.—ESTIMATED COMPOSITION OF CERTAIN TREATMENTS APPLIED TO TRUCK CROPS. POUNDS PER ACRE PER ANNUM

PLOT No.	*Treatment*[1]	*Fertilizing constituents*		
		Nitrogen	*Phos. acid*	*Potash*
		Lb.	*Lb.*	*Lb.*
25	Manure, 16 tons	144	64	128
28	Manure, 16 tons; superphosphate, 400 lb.	144	128	128
26	Manure, 16 tons; superphosphate, 400 lb., nitrate soda, 160 lb.	169	128	128
6	Nitrate soda, 320 lb.; superphosphate, 800 lb., muriate potash, 100 lb.	50	128	50
31	Nitrate soda, 160 lb.; superphosphate, 400 lb., muriate potash, 50 lb.	25	64	25
34	Nitrate soda, 160 lb.; superphosphate, 400 lb.	25	64	..

Value of increase and cost of treatment—The crops produced in this test are sold through the Marietta Truck Growers' Association, and during the first 8 years the prices averaged about 2 cents a pound each for cabbage and sweet corn, 3½ cents for tomatoes and 1½ cent for cucumbers. The prices have been somewhat higher during recent years, but using these prices, and rating fertilizing constituents at 23 cents a pound for nitrogen, 7 cents for phosphoric acid and 6 cents for potash,[2] we have the financial outcome shown in Table LXXX for the average of the 12 years, 1915-1926.

TABLE LXXX.—TWELVE YEARS AVERAGE ANNUAL VALUE PER ACRE OF INCREASE AND COST OF TREATMENT IN EXPERIMENT WITH TRUCK CROPS

PLOT No.	*Treatment*	*Value of increase*	*Cost of treatment*	*Balance*
		Dol.	*Dol.*	*Dol.*
25	Manure	145	44	101
28	Manure, superphosphate	152	49	103
26	Manure, superphosphate, nitrate soda	186	55	131
6	Nitrate soda, superphosphate, muriate potash	108	24	84
31	Nitrate soda, superphosphate, muriate potash	70	12	58
34	Nitrate soda, superphosphate	42	10	32

The reinforcement of manure with superphosphate has increased the yield of every crop, averaging about 5 percent, and the further reinforcement with nitrate of soda has caused an additional gain of 20 percent in the yield. That potash has not been unimportant is shown by the drop in increase when it is omitted, on Plot 34, although the effect of this constituent has been less uniform than that of nitrogen and phosphorus.

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[1] Over a basic treatment of one ton limestone.

[2] At these prices the value of a ton of manure would be about $2.20.

Probable equivalence of manure and chemicals—Considering this work as a whole, there does not seem to be any reasonable doubt that, if the nitrogen and potash had been brought up to the same level in the chemical as in the manure treatment the chemicals would have made as good a showing as the manure. The fact that chemical nitrogen acts more promptly than that in manure would suggest dividing the nitrogen applications, as has actually been done in this test, where nitrate of soda has been applied in one application on Plot 15 and in two on Plot 14—half at planting and half two or three weeks later—with a small advantage in favor of the divided dressing. But if wheat can thrive for

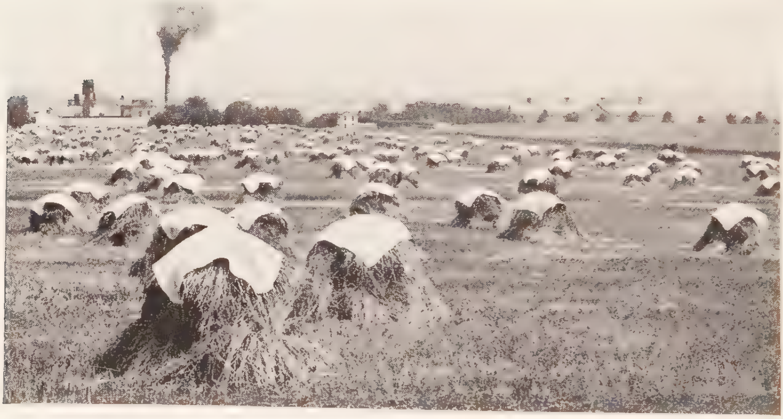

FIGURE XXVIII.—WHEAT IN FIELD CULTURE, OHIO EXPERIMENT STATION

Thirty-four bushels of wheat to the acre, which is a bushel less than the 23-year average yield on four 10-acre fields at the Ohio Experiment Station in a rotation of clover, corn, oats and wheat. The oats, which has averaged 63 bushels per acre during the same period, is shown at the right, and the corn, which is growing beyond the oats, is shown as it was harvested later the same season (1915), in Figure XXVII.

The wheat is a variety test, of 100 tenth-acre plots, which must be threshed from the field as it is impracticable to house or stack so many lots and keep them separate. But the covers protected the wheat through one of the wettest harvests Ohio has ever known, so that it was saved, without loss. Photo by E. J. Houser.

three-quarters of a century under an annual application of 129 pounds of chemical nitrogen per acre, as it has done in Broadbalk Field, giving under this treatment (combined with minerals carrying 64 pounds of phosphoric acid and 100 pounds of potash) an annual average yield of nearly 35 bushels per acre, and outyielding manure carrying more nitrogen, phosphoric acid and potash than have been given in the 16 tons of manure used on these truck crops, a similar outcome may reasonably be expected with these crops.

The mistake made in planning this experiment, for which the writer is responsible, was in overlooking the fact that in leaving clover out of the rotation we are dealing with practically the same problem as that presented in Broadbalk Field, for the soybean, grown only as a cover crop, cannot replace clover as a nitrogen collector.

Comparison of truck crop and field crop rotations—It is instructive to compare the outcome in this truck crop rotation with the rotation of corn, soybeans, wheat and clover which has been in progress on the Field Crop section of the same Washington County experiment farm over the same 12-year period. This is done in Table LXXXI, which shows the increase due separately to phosphorus, nitrogen, potash and limestone, given in percentages of the basic yields in the two tests.

TABLE LXXXI.—COMPARISON OF TRUCK CROP AND FIELD CROP ROTATIONS, SHOWING PERCENTAGE INCREASE DUE TO SEPARATE FERTILIZING CONSTITUENTS AND LIMESTONE

TREATMENT	*Percentage increase*			
	Truck crop rotation			
	Cabbage	*Tomatoes*	*Cucumbers*	*Sweet corn*
Nitrate soda	28	23	20	15
Superphosphate	3	8	1	2
Muriate potash	1	..	25	1
Limestone	14	5	5	6
	Field crop rotation			
	Corn	*Soybeans*	*Wheat*	*Clover*
Nitrate soda	3	2	96	18
Superphosphate	23	20	87	45
Muriate potash	6	—3	6	..
Limestone	13	25	53	56

The table shows that nitrogen, as carried in nitrate of soda, and phosphorus, as carried in superphosphate, have completely changed places in relative effectiveness in the two rotations, except for wheat. The clover, which in this test has averaged less than half a ton per acre on unfertilized and unlimed land, has contributed no more nitrogen than the corn required, and the soybeans have left no surplus, so that the wheat has been ready for all the nitrogen provided by the fertilizer. The relatively large effect of nitrate of soda on the clover in this test is explained by the neutralizing effect of this salt on acid soils, the soda having contributed more to the growth of clover than the nitrogen.

Possible use of clover in truck farming—The outcome of this test raises the question whether the truck farmer would not act wisely in a larger employment of clover as a collector of nitrogen. With the advent of auto trucks and improved roads a truck farm 20 miles from the city market would be actually nearer in point of time than one within 3 or 4 miles has been previous to this advent, and at this distance the lower cost of land would justify providing for the systematic production of clover in rotation with the truck crops.

A crop of clover turned under every third or fourth season would solve the problem of maintaining the supply of organic matter, and would leave the truck farmer free to choose between manure and chemicals, whichever would furnish the necessary chemical elements at the lowest cost.

Effect of lime—Although the Marietta truck farm is located within the region in which sandstones are the principal surface rocks, the fact that its soil has been built up as a river flood plain, with materials derived from the wash from many sources, would lead us to expect that it would be less deficient in lime than if it had been formed by the decomposition of the underlying sandstone, as in the case of the field crop section, which is located on a residual sandstone soil, and while cabbage has given a large and consistent response to liming that of the other crops has been but little more than sufficient to warrant its use.

CONCLUSIONS

The same general principles of fertilization apply to truck crops as to other crops, namely: Unless the nitrogen supply is maintained by the systematic growing of clover it must be kept up by the use of manure or of nitrogenous fertilizers; but while nitrogen will be the element of first importance in such fertilizers, it will be used wastefully if not accompanied by phosphorus and potassium.

The relatively high acre-value of truck crops justifies an expenditure for manuring or fertilizing that would be impractical with field crops, but the question should be carefully considered whether it may not be more economical, under modern conditions, so to enlarge the truck farm as to permit the use of clover than to depend wholly upon purchased fertility.[3]

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[3] These experiments with truck crops have been conducted by the Horticultural Department of the Ohio Experiment Station, under the immediate supervision of O. N. Riley, who has been foreman of the truck experiment farm since its establishment. The data used in the present discussion are compiled from Bul. 420, Ohio Exp. Station, prepared by Donald Comin and John Bushnell.

XXVIII

Review and Practical Applications

The investigations reported in the preceding pages have demonstrated the possibility of maintaining a very high rate of crop production by the use of chemical fertilizers alone. In all the history of agriculture there is no record of a yield of wheat equalling the 60-year average of 37 bushels per acre grown on Plot 8 in Broadbalk Field, two-thirds of which, that is, the excess over the unfertilized yield of 12.8 bushels, must be credited to chemical fertilizers.

Similar experiments, which are being made under widely different conditions of soil and climate, are showing that the outcome in this English wheatfield is not an accident, but that it is possible materially to increase the yield of crops on practically all soils by the use of similar fertilizers.

But while these experiments are demonstrating the physical possibility of thus converting the nitrogen of the air and the phosphorus and potassium of the rocks into bread, they are also showing that there must be a considerable reduction in the cost of combined nitrogen, or a considerable increase in the value of farm produce, before it can be made economically possible to depend upon chemicals alone for the production of food.

By a judicious use of chemicals, however, as supplements to a scientific rotation of crops and the careful saving of all crop residues, it is possible materially to increase the yield per acre and at the same time to reduce the unit cost of production on most soils. No scheme of management can be laid down which will be adapted to every farm, but the general principles of fertility maintenance are of universal application, and when these principles are clearly understood it is possible so to plan the management of a farm as to maintain its fertility with a small expenditure for fertilizers.

The chief points to be considered in planning the treatment of a farm or a field are as follows:

Geological history
Climatic conditions
Previous cropping and treatment
Market conditions
Adaptation of the farmer.

Geological history—If the soil has been derived from non-calcareous rocks it is to be expected that it will need lime at an earlier date than if limestones have contributed to its formation, either by weathering in place or by transportation; and if it has originated in granitic rocks it is likely to be better supplied with potassium than if it be a muck, or a limestone soil.

Climatic conditions have an important relation to soil management. In humid regions the nitrates and soluble mineral elements are continually being washed out of the soil by the rains and carried to the sea in the rivers, unless intercepted by the roots of growing vegetation; whereas in arid regions there is such an accumulation in the soil of available plant nutrients that when water is added by irrigation very large crop yields are obtained. Even in humid countries it has been observed that exceptional crops frequently follow a season of drought, due to the storing in the soil during the drought of nutrients which the crops were unable to make use of because of lack of water to dissolve them and carry them into the plant.

Differences in temperature not only determine whether such crops as cotton and the citrus fruits may be grown, but also materially affect the productiveness of crops within much narrower limits. Oats and potatoes thrive best in a climate which is too cool for corn; spring wheat prefers a cooler climate than that which is best for winter wheat, and different varieties of winter wheat sometimes have very decided climatic preferences. For these reasons the climatic conditions of the region in which a farm is located should be carefully studied in planning its management.

The previous treatment of the land is also an important factor. A field which has lain in pasture for many years is likely to be deficient in phosphorus, because of the drain made upon this element to build the skeletons or to furnish phosphorus for the milk of the animals which have fed upon its grass, whereas the nitrogen and potassium consumed in the grass would have been largely returned to the soil in the animal excrement; but a field that has been used for many years in grain production and from which all the crops have been removed will be hungry for all three of these elements unless its soil was abnormally supplied with one or all of them to begin with.

Market conditions are to be considered in planning a system of management. If the farm is located near a city the production of truck crops, small fruits and milk may be carried on to better advantage than when the distance to market is greater, while the distance from railway or water transportation may be so great as to make it necessary that the products of the farm shall be chiefly converted into beef, to be driven to market on foot, or into butter, cheese or wool, in which large values can be concentrated in relatively small weight.

The adaptation of the farmer—Finally, the personal equation must be taken into consideration; that is, the preferences and general adaptation of the farmer himself. Men succeed best in the work in which they take most interest. A man may make an excellent truck or grain farmer who would be a failure in handling livestock. A successful meat producer may make a miserable failure in dairying or wool growing or poultry keeping. Happily, there is room enough yet for everybody, and work enough of all kinds from which to choose. Fortunate is the man who has found his place in the work of the world.

A few illustrations—While, therefore, no definite rules can be laid down which every farmer in every locality may successfully follow, we may draw from the experiments reported in the preceding pages some suggestions that will have wide applications in farm practice. Let us take for illustration a farm somewhere in the Upper Mississippi Valley; one that has been in cultivation half a century or more.

Drainage—If the farm is underlaid with gravel or stratified rocks at a depth not exceeding 3 to 5 feet, underdrainage may not be necessary; but if it is not thus naturally drained artificial drainage must be supplied before its rate of production and consequent value per acre can equal that of drained land of the same quality in other respects.

The cost of drainage will of course vary with different conditions of soil. Except in the stiffest clay soils it is seldom necessary to lay the drains closer together than 4 rods, or at the rate of 40 rods of drain per acre. At a dollar a rod, which is more than the average cost should be, the cost would be $40 an acre. The interest on this cost would be paid by 3 or 4 bushels of corn, or 2 or 3 bushels of wheat; but for land that really needs draining much larger average increases than these may reasonably be expected to follow proper drainage. It is quite true that in some seasons undrained land may produce as well as that which has been drained, but drainage improves the chances in both wet and dry seasons and thus raises the general average yield. Moreover, drainage reduces the cost of production by making it possible to get onto the land earlier in the spring and sooner after rains, and thus there is less time lost in waiting on the weather and the labor of men and teams is distributed to better advantage.

Drainage is a permanent improvement, belonging to the same category with buildings. Every dollar judiciously invested in drainage is a dollar added to the productive capital of the farm; a dollar added to the actual value of the soil.

Lime—Our farm will lie upon one of two great types of soil; either one supplied with lime through the decomposition of underlying rocks or through glacial or fluvial detritus transported from limestone formations, or one deficient in lime because of having been derived chiefly from non-calcareous rocks. The superior productiveness of a limestone soil has been observed ever since man began to study the soil; but a partial offset to this superiority is found in the fact that the non-calcareous soils are frequently much the more easily worked of the two classes.

Comparison of a limestone with a sandstone soil—The field experiments with fertilizers at the Pennsylvania Station are located on a soil derived from the decomposition of limestones, which lie so near the surface as to afford natural drainage. The soil of the Ohio Station at Wooster lies over shaly sandstones, from which it has been largely derived, though somewhat modified by glacial drift. In this case, however, the drift is a comparatively thin sheet containing very little lime.

The Pennsylvania experiments were begun in 1882, and those of the Ohio Station in 1894. Since 1900 the Ohio experiments have been divided into two portions, one-half being dressed with lime or powdered limestone once every five years, while the other half is left unlimed. The lime has been spread on all the land, fertilized and unfertilized alike, at a rate equivalent to an average of about a ton and a half of ground limestone per acre per rotation, equivalent to 600 pounds per acre per annum.

The cropping in these experiments is a 4-year rotation of corn, oats, wheat and clover in Pennsylvania, and a 5-year rotation of corn, oats, wheat, clover and timothy in Ohio.

Table LXXXII.—A Comparison of a Limestone and a Sandstone Soil. Treatment and Values per Acre per Annum

	Fertilizers		
	Super-phosphate	*Muriate potash*	*Nitrate soda*
Station	*Lb.*	*Lb.*	*Lb.*
Pennsylvania	75	100	75
Ohio	56	52	96

	Value of crops		
Treatment	*Pennsylvania*	*Ohio*	
		Unlimed	*Limed*
None	$17.61	$12.77	$17.35
Phosphorus alone	22.67	18.91	23.18
Phosphorus and potassium	25.16	21.85	27.81
Phosphorus, potassium and nitrogen	30.30	26.88	31.02

The rate of fertilizing has not been the same in the two tests, phosphorus and potassium having been given in larger quantities in Pennsylvania and nitrogen in larger quantity in Ohio, as shown in Table LXXXII, which also shows the annual value of the crops produced by various treatments, for the 40 years, 1882-1921 in Pennsylvania and for 35 years, 1894-1928 in the Ohio test, excluding the timothy crops in this rotation and computing it as the same 4-year rotation of corn, oats, wheat and clover as that of the Pennsylvania test, and rating corn at 80 cents a bushel, oats at 50 cents, wheat at $1.25 and hay at $12 a ton in both tests.

The table shows that on the unlimed land in the Ohio test the yields in every case have fallen below those of the similarly fertilized land in the Pennsylvania test, but when lime has been applied the yield of the unfertilized land in Ohio is brought up to practically the same level as that on the unfertilized Pennsylvania land, while the combination of lime and fertilizers has produced larger yields in Ohio than the fertilizers alone have done in Pennsylvania.

It would not be justifiable to draw from this one comparison the conclusion that any non-calcareous soil may be brought up to the level of any limestone soil by the addition of a little pulverized limestone, as in both classes of soils there are differences in natural fertility and in responsiveness to treatment; but the results show that, to a greater or less extent the lack of lime is a defect that may be remedied.

In the case of the Ohio land the cost of the liming, for material and labor, has been equivalent to nearly two dollars per acre annually. The table shows that this cost has been recovered with interest in addition at the rate of more than 100 percent.

As between the two farms on which these experiments are being conducted, therefore, it appears that an expenditure of two dollars per acre annually in lime or limestone has fully offset any difference in the natural fertility of the soil.

Of course the productive capacity of the land is but one of several factors which enter into the value of a farm. Buildings, roads and market facilities must also be considered, saying nothing of schools, churches and other social conditions.

Phosphorus—The table shows that in both experiments and on both limed and unlimed land phosphorus has produced a marked increase in yield, and many other experiments in different parts of the world have shown that this outcome in these two long-continued experiments is by no means exceptional.

The ultimate function of agriculture is to feed and clothe humanity, and the most important mineral element in human food is phosphorus. Under existing conditions the greater part of the phosphorus consumed by mankind eventually finds its way to the sea or to the cemetery, so that there is a steady flow of this element from the soil which is never returned. Wherever, therefore, the land has been under cultivation for any considerable length of time there will be a deficiency of phosphorus, except in the rare instances in which the soil has been naturally stocked with an abnormal supply of this element.

The annual cost of the phosphorus has been about $1.30 per acre in the Pennsylvania tests, and 60 cents in the Ohio experiments. The return for these expenditures has been several times their cost in both these tests and on both limed and unlimed land, as it has been in the great majority of the tests listed in Table XIX. (See Appendix.)

Potassium—The experiments hereinbefore described have shown that deficiency of the soil in potassium is usually shown at a later date than that of phosphorus, but the potassium supply may eventually become the more important of the two. The response of some of the older soils in the eastern states to potash fertilizing is suggestive, while the indifference of some soils is a warning that it is quite possible to waste money in this direction. The sensitiveness of the potato to potash deficiency would suggest the use of this plant as a means for determining the need for potash treatment. See Figure IX, page 149.

Nitrogen—The paramount importance of nitrogen in crop production is shown in the 74 years average yields at Rothamsted of 13½ bushels of wheat per acre when everything except nitrogen was provided in abundance and 34½ bushels when nitrogen was added; but the cost of this added nitrogen at 3½ cents a pound for nitrate of soda would be about a dollar for each bushel of increase, saying nothing of the cost of harvesting and marketing this increase.

Corn suffers even more quickly from total deprivation of nitrogen than wheat, as shown in the Ohio experiments in continuous cropping, hence the maintenance of the supply of this element through some other medium than chemicals becomes imperative if our crops are to be grown with profit.

Crop rotation—Through the clovers, and to a less extent through other leguminous crops, we have access to the limitless supply of atmospheric nitrogen, which these crops will procure for us and pay for the privilege of doing it. The culture of such crops is therefore the foundation of an economical system of farming.

For the successful growth of red clover, alfalfa or melilot an abundant supply of lime in the soil is indispensable. Where lime is deficient and its cost is prohibitive the soybean may be substituted, although this plant also requires lime for its most perfect development.

It is not too much to say that the farmer who has not become convinced of the paramount importance of a systematic use of the leguminous crops has missed the master key to success in his operations.

Farm manure is another source of nitrogen, but whether a cheaper or a more expensive source of this element than chemicals depends upon whether it is produced on the farm under such conditions that there shall be no financial loss in handling the animals producing it, and whether it be so cared for that the larger part of its value shall not be lost before it reaches the field. It is easily possible for manure to be made a more costly source of fertility than chemicals if it be purchased at a high price and transported a long distance, or permitted to lie exposed to the weather until its fertilizing elements have been leached out by rain. Moreover, manure at best is an incomplete fertilizer, because the animals producing it have appropriated a considerable part of the phosphorus contained in their food for the production of bone and milk, and the experiments hereinbefore considered have shown that when phosphorus is deficient neither nitrogen nor potassium can have their full effect.

Treatment of manure—In the average of the 30 years during which the test described in Chapter XXI has been in progress, the manure taken to the field in January and spread at once has produced 69 bushels of corn, 30 bushels of wheat and 4,830 pounds of hay per acre per annum, as against 57 bushels of corn, 24 bushels of wheat and 3,700 pounds of hay harvested from the same original quantity and kind of manure, thrown into the barnyard in January and left there until April, differences having an annual value of nearly $8.00 per acre, at the prices hereinbefore employed, and secured at an annual cost of 100 pounds of superphosphate, together with the small amount of additional labor required to harvest the larger yields, an item fully offset by the greater value of the land for future crop production.

In this test wheat has followed corn and has had no direct fertilizing. It is probable that its yield might have been increased by a small direct application of superphosphate in addition to that given with the manure.

Substitution of ten-acre fields for tenth acre plots—This inference is supported by another test on this farm, in which four 10-acre fields have grown corn, oats, wheat and clover in a 4-year rotation since 1894, each crop being grown every year. For 12 years the treatment consisted in the application of about 10 tons of common, open-yard manure as a top dressing to the wheat, no other fertilizer being used. During this period the average annual yields per acre were 48 bushels each of corn and oats, 21 bushels of wheat and 3,500 pounds of hay. The treatment was then changed, the manure being reinforced with superphosphate, 40 pounds per ton of manure, and kept under shelter until fall, when it was spread on the clover sod, to be plowed under the following spring for corn. After plowing, the land received 2 tons of powdered limestone per acre. The oats received no treatment, but 300 pounds of superphosphate and 50 pounds of muriate of potash were applied with the wheat, followed with an average of about 60 pounds of nitrate of soda in the spring, the nitrate being omitted when the spring growth was rank.[1] Since this change was made the 23 years average yields per acre have been 76 bushels of corn, 63 bushels of oats, 35 bushels of wheat and 6,100 pounds of hay. Computing the gain in yield at the prices hereinbefore employed it has amounted to $15.75 per acre annually, secured at an expenditure for liming and fertilizing amounting to $5.30 per annum, assuming that the cost of manuring has been the same throughout both periods. (See Figures XXVII and XXVIII.)

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[1] This treatment on wheat has been changed during recent years to 400 lbs. 2-12-2 formula applied in the fall.

Of course this is not an exact comparison, as seasonal differences may have affected the results, but there can be no question that the more liberal treatment during the later years has been amply justified by the results.

It will be observed that the yields in this test are computed on 10-acre fields, and not on tenth-acre plots.

Comparing the two rotations, the corn has given 7 bushels per acre more in the 4-year than in the 3-year test, but it has received 2 tons per acre more manure, although the total dressing of manure has amounted to 2 2-3 tons per acre per annum for the entire rotation in the 3-year test and 2½ tons in the 4-year test. The unfertilized yield of wheat following corn has been 5 bushels less than the fertilized yield following oats, a difference that would pay for the phosphorus and potassium given to the wheat with a profit, but would barely cover the cost of the nitrogen.

Purchase of nitrogen of doubtful economy—It is very doubtful whether, in so short a rotation as this, with clover averaging 3 tons of hay an acre and with farm manure cared for and used as in this test, there will be any occasion for the purchase of additional nitrogen. The yield of wheat thus far obtained—35 bushels per acre—is the average yield of a large number of different varieties, this being primarily a variety comparison, and the general average has been reduced by the inclusion of a number of inferior sorts. As it stands, it has not been exceeded by any authenticated yield, considering its duration, except the yields of 37.6 bushels per acre attained as a 34-years average from mineral fertilizer only, and of 39 bushels from the same minerals reinforced with nitrogen, in the potatoes-wheat-clover rotation on the same farm.

Livestock farming vs. grain farming—The yield of wheat in this potato rotation has been obtained without the aid of any animal manure or of any organic matter except the crop roots, potato tops and clover aftermath, the hay having been removed from the land, thus adding this test to the evidence that the function of manure in fertility maintenance is to conserve the nitrogen and mineral elements of the crops fed, for the benefit of those that follow. This leads to the question whether the same object may not be attained by returning to the land all its produce except the grains and purchasing only the elements removed from the land in these grains.

An investigation of this problem is being conducted on the same farm in which a uniform tract of 9 acres is divided into 2 equal parts, one of which is given to livestock farming, the other to grain farming. The crop rotation is corn, soybeans, wheat and clover, each crop being grown every year. In the livestock system all the crops except the wheat and cloverseed, when cloverseed is harvested, are either fed to livestock or pass into the manure as bedding.

The livestock is kept in a large box stall, heavily bedded on cement floor under cover, so that all the manure, both solid and liquid, is saved. The stable is not cleaned until the feed is consumed, when the manure is hauled to the field and spread on the land that is to be planted in corn on the livestock section the following spring. Each livestock acre, accordingly, receives the manure from 4 acres of produce every fourth year, the amount depending upon the size of the crops of the preceding year.

In the grain farming system the corn is husked on the stalk, the stover being left on the ground to be plowed under for soybeans. The soybeans and wheat are cut and threshed. The soybean straw, together with a small part of the wheat straw, is spread early in the winter on the wheat stubble over the young clover; the remainder of the wheat straw is spread during the winter on the old clover that is to go into corn the following year. No hay is taken off the land. The general practice has been to let the hay crop stand without mowing; the entire crop, with the added straw, being plowed under for corn.

Both tracts receive per acre on corn 2 tons of ground limestone and 400 pounds of 16 percent superphosphate, and on wheat 300 pounds of superphosphate. All the land is underdrained with tile drains 36 feet apart. In all the operations except as specified both tracts receive the same treatment. In Table LXXXIII the results of this test are given for 16 years, as reported by Director Williams in Bulletin 402 of the Ohio Experiment Station.

TABLE LXXXIII.—CROP YIELDS AND MANURE PRODUCTION IN LIVESTOCK AND GRAIN FARMING TEST, OHIO EXPERIMENT STATION

	1st rotation	*2nd rotation*	*3rd rotation*	*4th rotation*	*16-year average*
Corn (bu.)					
Livestock	61.8	67.3	78.6	86.6	73.5
Grain	52.8	64.4	69.6	80.2	66.7
Difference	9.0	2.9	9.0	6.4	6.8
Soybeans (bu.)					
Livestock	25.2	19.4	20.4	26.1	22.6
Grain	21.1	17.4	18.0	22.4	19.6
Difference	4.1	2.0	2.4	3.7	3.0
Wheat (bu.)					
Livestock	33.4	35.6	34.5	31.9	33.9
Grain	27.5	32.0	31.2	29.5	30.2
Difference	5.9	3.6	3.3	2.4	3.7
Clover (tons)					
Livestock	2.43	2.06	2.22	2.29	2.24
Manure produced in livestock system (tons)	... [2]	13.4	15.6	17.8	15.5[3]

Table LXXXIII shows that the yields in the livestock system have been larger for each period than those in the grain farming system. An adequate explanation of this outcome is found in the fate of the crop residues under the two systems of management. In the one case these are all carefully saved and returned to the land saturated with the digestive liquids; in the other the corn stover is left standing, some of it to be blown out of the field and all of it, together with the straws and clover, to lose a considerable part of their proteid constituents through eremacausis, the nitrogen, freed from its combinations, escaping into the atmosphere. The difference in the crop yields, as shown in this table, would account for about one-third as much nitrogen as that carried in the residues under the livestock system; nitrogen that has been permitted to escape instead of being put to work again in the production of new crops.

It does not necessarily follow that the livestock system is more economical than the grain farming system. That question depends upon the relative labor cost of the two methods, upon the ability of the individual farmer to handle livestock successfully, and upon the carefulness with which

[2] Weights of manure not determined.

[3] 13-year average.

manure is handled. Were the manure to be subjected to the neglect practised on too many farms and illustrated in Chapter XXI, the grain farming system, if rigorously carried out, would probably give the larger yields.

This experiment has shown that under both systems rates of yield far above the average of the State are being maintained without the purchase of any soil improving or fertilizing material except limestone and superphosphate, and that thus far there is no definite evidence of declining yield, although of course the test must be carried much farther before positive conclusions on this point will be justified.

The dominant position of combined nitrogen—In 1898 Sir William Crookes, in an address before the American Association for the Advancement of Science, called attention to the dominant position of combined nitrogen in crop production, and to the fact that unless some method were discovered by which the supply of such nitrogen might be increased beyond that furnished by the nitrate beds, coal mines and other sources then being drawn upon, the time would come before many years when the world would not be able to feed its rapidly increasing population.

The real object of this address was to announce the discovery of a method of combining atmospheric nitrogen, which promised to solve the nitrogen problem for the farmer by bringing the illimitable store of nitrogen in the air within his reach. This method has since been developed and improved upon until today the combinations of atmospheric nitrogen are constituting a large and steadily increasing part of the nitrogen in commercial fertilizers.

The lecturer failed to give sufficient prominence to two important points: 1: the vast areas of land that are still unused or are merely being skimmed over, and 2: the potential value of leguminous crops for the capture of nitrogen.

On the first point, Prof. F. H. King, in his "Farmers of Forty Centuries,"[4] pointed out that in Japan, Korea and China nearly 500,000,000 people are being maintained, chiefly upon the products of an area smaller than the improved farm lands of the United States, and without the use of chemical fertilizers of any kind.

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[4] Mrs. F. H. King, Madison, Wisc., 1911.

The capture of nitrogen by clover—On the second point, the investigations herein reported are demonstrating the economic practicability of very greatly increasing the yield of the land by the systematic capture of nitrogen through the employment of the clovers, reinforced by the mineral phosphates and potassic salts, the natural stores of which have merely been surface scratched. While, therefore, it would be futile to say that the time can never come when the earth will not be able to feed its children, it is evident that that time is very remote.

This point is emphasized by the fact that at this day, when the scarcity of food predicted by Crookes should be in evidence—for the added supply of nitrogen due to the discoveries he announced has not yet contributed in any important measure to our food supply—we hear from all quarters in America the complaint that we are producing too much food and are thereby reducing its price below the point of profitable production.

Reduction of cost of production—But the trouble is, not that we are producing too much food, but that we are producing it at too high a cost and that the world's system of distribution is too imperfect.

In the 5-year rotation at the Ohio Experiment Station certain areas of land receive no treatment except liming. The 35 years annual value per acre of the produce of these areas has been $17. On adjoining land superphosphate has been applied at a rate equivalent to an annual dressing of 56 pounds of the 16 percent grade per acre, a treatment that has increased the annual value of the produce by $5. Deducting the cost of the fertilizer and 25 percent of the increase to cover the cost of harvesting the extra crop produced, there has been a net gain of $3, making a total value of $20 produced at the same cost for land rental, seed and labor as the $17 on the untreated land, and reducing the cost per unit of crop to 85 percent. In other words, if it cost one dollar to produce a bushel of wheat on the untreated land it has cost but 85 cents to produce it on the phosphated land.

When the equivalent of 52 pounds of muriate of potash annually has been added to the superphosphate, the annual total value of the increase has been $9 and its net value $5, reducing the cost per unit to 78 percent of that on the untreated land.

The further addition of nitrate of soda to the treatment has increased the annual value of the produce by a considerable amount, but not sufficiently to cover the cost of the nitrogen at present prices. So long, therefore, as the cost of fertilizer nitrogen is so great as it is at present its purchase cannot be recommended on the outcome of this test for ordinary farm crops.

These results, of course, would not be exactly duplicated on every farm, but it is absolutely safe to say that the possibility of materially reducing the cost of the bushel of grain or the ton of hay lies within the grasp of the average farmer. Some farmers are already realizing this possibility.

The bugbear of overproduction need not be feared. The world is not producing too much food. In this good year, 1929, millions of people are starving in China, while the price of wheat on American farms is below the normal price of commodities in general. In this good year, moreover, if the people of Ohio—a state that usually produces a surplus of wheat—were dependent upon the wheat grown in Ohio last year for their bread there would be many hungry people in this rich state, for many counties in Ohio in 1928 failed to produce enough wheat for the next year's seeding, and the yield for the state as a whole was less than half the requirement of its people for seed and bread, and yet this failure has had a very insignificant effect on the price of the loaf in Ohio, because of the abundant crop in other regions.

When the mechanism of distribution, the world over, becomes as perfect as in the United States; and when the Nations of the world have learned to live together under the Pact of Paris as amicably as do the different states of our Union, instead of fighting each other with armies and navies and unfriendly legislation, famine will have lost its terrors.

One feature of the present situation should not pass unnoticed, and that is that, if the millions of young men who were slaughtered in the World War had been left alive, they, with the families that would be growing up around them, and with the wealth that would have been saved from destruction, would be consuming all the food that the world is producing today, and at better prices than those now prevailing.

APPENDIX

Table XIX

Summary of Experiments in Liming and Fertilizing Field Crops Grown in Rotation

TABLE XIX.—SUMMARY OF EXPERIMENTS IN LIMING AND FERTILIZING FIELD CROPS GROWN IN ROTATION
PART I: SOILS, DURATION OF TESTS, CROPS IN ROTATION AND BASIC TREATMENT

TEST	*Station*	*Soil Series*	*Years*	*Crops in rotation*	*Basic treatment*	*Test*
No.	EASTERN OHIO		No.			No.
1	Wooster	Wooster	10	Corn, oats, wheat, clover, timothy	None	1
2	Wooster	Wooster	25	Corn, oats, wheat, clover, timothy	None	2
3	Wooster	Wooster	25	Corn, oats, wheat, clover, timothy	Limestone	3
4	Wooster	Wooster	14	Corn, oats, wheat, clover	Manure, superphosphate	4
5	Wooster	Wooster	14	Corn, oats, wheat, clover	Limestone	5
6	Wooster	Wooster	23	Corn, oats, clover	None	6
7	Wooster	Wooster	31	Corn, wheat, clover,	Manure, limestone	7
8	Strongsville	Trumbull	10	Corn, oats, wheat, clover	None	8
9	Strongsville	Trumbull	16	Corn, oats, wheat, clover	Limestone	9
10	Strongsville	Trumbull	16	Corn, oats, wheat, clover	Raw phosphate	10
11	Strongsville	Trumbull	21	Corn, oats, clover	Manure	11
12	Trumbull Co.	Trumbull	10	Corn, oats, wheat, clover	Manure, superphosphate	12
13	Trumbull Co.	Trumbull	10	Corn, oats, wheat, clover	Limestone	13
14	Mahoning Co.	Canfield	10	Corn, oats, wheat, clover	Limestone	14
15	Mahoning Co.	Canfield	10	Corn, oats, wheat, clover	Limestone	15
16	Belmont Co.	Muskingum	10	Corn, wheat, clover, timothy	None	16
17	Washington Co.	Muskingum	12	Corn, soys, wheat, clover	None	17
18	Washington Co.	Muskingum	12	Corn, soys, wheat, clover	Manure	18
19	Carpenter	Muskingum	24	Corn, wheat, clover	None	19
	WESTERN OHIO					
20	Paulding Co.	Fulton	15	Corn, oats, wheat, clover	None	20
21	Paulding Co.	Fulton	14	Corn, soys, wheat, clover	None	21
22	Hancock Co.	Miami	13	Corn, oats, wheat, clover	None	22
23	Miami Co.	Miami	16	Corn, oats, wheat, clover	None	23
24	Miami Co.	Miami	16	Corn, soys, wheat, clover	None	24
25	Miami Co.	Miami	16	Corn, corn, oats, clover	None	25
26	Miami Co.	Miami	12	Corn, wheat, clover	None	26
27	Madison Co.	Miami	8	Corn, corn, wheat, clover	None	27
28	Germantown	Miami	24	Corn, wheat, clover	None	28
29	Hamilton Co.	Clermont	14	Corn, soys, wheat, clover	None	29
30	Clermont Co.	Cincinnati	13	Corn, soys, wheat, clover	None	30
	PENNSYLVANIA					
31	State College	Hagerstown	25	Corn, oats, wheat, clover	None	31

TABLE XIX.—PART I (*Continued*)

32	State College	Hagerstown	15	Corn, oats, wheat, clover	None	32
	VIRGINIA					
33	Blacksburg	Hagerstown	18	Corn, wheat, clover, timothy	None	33
	DELAWARE					
34	Newark	Sassafras	15	Corn, soys, wheat, clover	None	34
	INDIANA					
35	Scottsburg	Volusia	20	Corn, wheat, clover	None	35
36	Scottsburg	Volusia	20	Corn, wheat, clover	Limestone	36
37	Moses Fell	Cincinnati (?)	9	Corn, soys, wheat, clover	Limestone	37
38	Moses Fell	Cincinnati	9	Corn, soys, wheat, clover	Limestone, manure	38
39	Worthington	Dekalb (?)	11	Corn, wheat, clover	Limestone, manure	39
40	Francisco	Dekalb	9	Corn, wheat, clover	None	40
41	Francisco	Dekalb	9	Corn, wheat, clover	Limestone	41
	KENTUCKY					
42	Berea	Dekalb	13	Corn, soys, clover	Manure	42
43	Berea	Dekalb	13	Corn, soys, clover	Manure, limestone	43
44	Fariston	Dekalb	10	Corn, soys, clover	None	44
45	Fariston	Dekalb	10	Corn, soys, clover	Limestone	45
46	Greenville	Dekalb	10	Corn, soys, wheat, clover	Manure	46
47	Greenville	Dekalb	10	Corn, soys, wheat, clover	Manure, limestone	47
48	Russellville	Decatur	11	Corn, soys, wheat, clover	Manure	48
49	Russellville	Decatur	11	Corn, soys, wheat, clover	Manure, limestone	49
50	Lone Oak	Loess	13	Corn, soys, wheat, clover	Manure	50
51	Lone Oak	Loess	13	Corn, soys, wheat, clover	Manure, limestone	51
52	Mayfield	Loess	12	Corn, soys, wheat, clover	Manure	52
53	Mayfield	Loess	12	Corn, soys, wheat, clover	Manure, limestone	53
			Potato and Tobacco rotations			
54	Wooster, Ohio	Wooster	15	Potatoes, wheat, clover	None	54
55	Wooster, Ohio	Wooster	15	Potatoes, wheat, clover	Limestone	55
56	Hamilton Co., Ohio	Cincinnati	13	Potatoes, wheat, clover	None	56
57	Clermont Co., Ohio	Clermont	11	Potatoes, wheat, clover	None	57
58	Montgomery Co., Ohio	Miami	24	Tobacco, wheat, clover	None	58
59	Miami Co., Ohio	Miami	12	Tobacco, wheat, clover	None	59
60	Greenville, Ky.	Dekalb	10	Tobacco, wheat, clover	Limestone	60
61	Mayfield, Ky.	Loess	10	Tobacco, wheat, clover		61

TABLE XIX.—PART II: BASIC YIELDS, GAIN FROM LIMING, SUPERPHOSPHATE APPLIED AND INCREASE

TEST No.	*Corn*				*Oats or Soybeans (s)*				*Wheat*		Test No.
	Basic yield Bu.	*Gain from liming Bu.*	*Superphosphate*		*Basic yield Bu.*	*Gain from liming Bu.*	*Superphosphate*		*Basic yield Bu.*	*Gain from liming Bu.*	
			Applied Lb.	*Increase Bu.*			*Applied Lb.*	*Increase Bu.*			
					Over sandstones and shales, unlimed						
1	31.36	....	70	6.86	29.61	...	70	6.45	8.91	...	1
2	17.87	11.14	75	7.62	28.00	8.53	75	10.98	9.70	4.82	2
4	53.38	14.25	...	...	53.67	2.77	...	...	26.29	3.27	4
6	39.63	10.62	320	8.93	40.60	4.88	...	4.81	...	...	6
8	23.26	....	70	8.68	34.80	...	70	10.55	5.62	...	8
11	33.77	11.47	320	8.47	41.12	5.69	...	9.51	...	...	11
12	40.86	7.78	...	...	42.91	4.84	...	...	20.65	4.17	12
16	47.53	11.66	200	7.81	....	...	...	...	8.88	3.97	16
17	36.20	5.78	200	8.26	s15.17	s3.85	100	s3.13	6.66	3.56	17
18	39.41	3.91	250	3.73	s18.32	s3.41	...	s—.70	8.65	3.49	18
19	23.67	....	120	8.80	....	...	...	...	8.23	...	19
35	19.40	5.90	92	12.70	....	...	...	...	6.70	1.30	35
40	34.30	10.40	...	...	....	...	...	...	6.30	3.00	40
42	28.90	10.00	460	8.60	s18.00	s5.30	...	s3.80	...	...	42
44	9.20	7.70	400	16.70	s 8.20	s3.64	400	s5.92	...	...	44
46	18.20	2.30	480	7.80	s 8.01	s4.05	...	s6.37	2.00	1.50	46
					Over sandstones and shales, limed						
3	29.01	....	75	4.84	36.53	...	75	8.58	14.52	...	3
5	52.19	....	250	9.40	53.12	...	250	3.71	23.70	...	5
7	59.50	....	320	10.42	....	...	...	...	24.35	...	7
9	24.76	....	75	11.37	36.15	...	75	14.69	12.43	...	9
10	30.88	....	75	...	45.70	...	75	6.34	20.60	...	10
13	22.57	....	200	5.96	43.92	...	100	7.35	17.77	...	13
14	40.96	....	200	5.69	44.35	...	100	5.50	12.18	...	14
15	37.70	....	200	7.72	s15.80	...	100	s2.79	11.80	...	15
36	26.30	....	92	7.80	....	...	...	...	7.50	...	36
39	46.30	....	200	3.60	....	...	...	...	12.40	...	39
41	44.70	....	...	3.40	....	...	...	...	9.30	...	41
43	38.90	....	460	7.50	s22.30	...	...	s3.42	...	...	43
45	17.80	....	400	24.00	s13.02	...	400	s12.24	...	...	45
47	25.15	....	480	13.30	s11.40	...	...	s7.47	4.85	...	47

TABLE XIX.—PART II (*Continued*): BASIC YIELDS, GAIN FROM LIMING, SUPERPHOSPHATE APPLIED AND INCREASE

TEST No.	*Corn*				*Oats or Soybeans (s)*				*Wheat*		*Test No.*
			Superphosphate				*Superphosphate*				
	Basic yield Bu.	*Gain from liming Bu.*	*Applied Lb.*	*Increase Bu.*	*Basic yield Bu.*	*Gain from liming Bu.*	*Applied Lb.*	*Increase Bu.*	*Basic yield Bu.*	*Gain from liming Bu.*	
					Over limestones						
22	29.75	2.93	120	5.52	29.15	1.34	120	4.70	6.95	1.26	22
23	46.90	1.86	200	13.05	45.67	—.55	100	8.56	13.14	.58	23
24	55.30	....	200	8.43	s21.07	...	100	s2.28	15.01	...	24
25	a86.36	a4.30	a200	a21.68	44.89	—.42	100	10.09	...	...	25
26	42.51	1.33	200	3.15	....	...	...	...	8.82	.31	26
27	a87.50	....	160	a8.37	....	...	...	...	15.06	...	27
28	37.37	.25	120	6.30	....	...	...	...	10.72	.84	28
29	43.12	3.08	200	5.04	s13.72	s .52	100	s1.50	12.52	2.28	29
30	20.94	2.72	200	6.96	s 7.44	s1.64	100	s2.23	6.08	4.58	30
31	36.30	5.76	300	11.60	30.78	1.91	...	4.62	11.40	1.60	31
32	17.90	4.52	300	18.53	27.62	2.82	...	12.31	10.02	1.20	32
33	38.31	....	377	12.32	....	...	...	...	7.31	...	33
37	22.40	5.00	225	17.20	s11.30	s1.90	...	s4.80	1.90	...	37
38	42.70	....	225	7.60	s11.20	...	...	s4.70	4.90	...	38
48	32.20	8.70	480	7.10	s12.80	s4.10	...	s2.67	11.07	.20	48
49	38.70	...	480	6.20	s16.60	...	...	s .63	10.20	...	49
			Unclassified 50 to 53, Kentucky loessal soils, 34 Delaware coastal plain								
50	34.02	5.20	480	.80	s16.36	s2.04	...	s .65	11.25	.70	50
51	36.20	....	480	.50	s16.20	...	...	s2.56	10.80	...	51
52	28.70	8.20	480	.70	s13.84	s5.23	...	s1.87	6.30	4.10	52
53	36.90	....	480	2.30	s19.07	...	...	s1.80	10.40	...	53
34	42.70	.40	250	.65	s14.60	s .50	250	s .93	10.40	...	34
20	54.65	—1.53	200	.72	61.69	—2.08	100	—2.37	28.81	—1.17	20
21	55.44	....	200	.07	s16.90	...	100	s1.40	25.29	...	21
54	p67.66	....	160	p14.96	....	...	...	...	31.14	...	54
55	p89.67	....	160	p—2.08	....	...	...	...	27.35	...	55
56	p56.76	....	200	p 2.12	....	...	...	...	32.95	...	56
57	p37.20	....	200	p10.13	....	...	...	...	14.43	...	57
58	t 5.56	....	480	t 2.01	....	...	...	...	13.89	...	58
59	t11.24	....	480	t 1.76	....	...	...	...	25.00	...	59
60	t 3.58	t—.13	360	t 4.70	....	...	...	...	7.20	2.30	60
61	t 6.24	t 1.22	360	t 1.96	....	...	...	...	6.60	9.60	61

[a] Two crops; s—soybeans; p—potatoes; t—tobacco.

TABLE XIX.—PART II (*Continued*): BASIC YIELDS, GAIN FROM LIMING, SUPERPHOSPHATE APPLIED AND INCREASE

	Wheat		*Hay*								
	Superphosphate						*Gain for liming*		*Gain for phosphate*		
TEST No.	*Applied Lb.*	*Increase Bu.*	*Basic yield Cwt.*	*Gain for liming Cwt.*	*Gain for phosphate Cwt.*	*Value Basic yield Dol.*	*Per acre Dol.*	*Per ton limestone Dol.*	*Per acre Dol.*	*Per 100 lb. phosphate Dol.*	*Test No.*
Over sandstones and shales, unlimed											
1	140	6.47	16.10	....	3.36	15.17	...	....	4.86	6.94	1
2	150	8.35	a31.13	a14.87	6.75	11.82	5.62	14.06	5.21	8.14	2
4	...	...	30.03	7.83	...	30.10	5.39	10.78	...	...	4
6	...	...	26.00	12.85	1.81	22.57	c5.40	16.20	3.30	3.09	6
8	140	7.14	13.20	...	9.04	12.74	...	....	6.64	9.48	8
11	...	...	21.41	7.68	9.30	20.64	c5.55	16.63	5.70	5.34	11
12	...	...	20.46	8.09	...	22.98	4.68	9.35	...	...	12
16	200	3.34	18.10	15.17	3.08	20.00	7.79	13.35	4.42	3.32	16
17	200	5.79	9.59	5.41	4.30	16.45	c4.52	18.09	5.28	4.22	17
18	250	4.90	11.58	2.89	1.74	19.19	c3.59	14.36	2.27	1.82	18
19	120	6.15	10.50	...	2.41	11.84	...	....	5.34	6.70	19
35	150	3.80	2.55	2.56	3.07	8.47	2.03	24.20	5.58	6.90	35
40	...	...	13.01	9.19	...	14.37	5.86	17.58	...	...	40
42	...	...	4.16	2.33	2.54	17.54	5.78	18.50	4.70	3.02	42
44	...	...	1.00	2.90	7.21	6.75	4.45	10.70	8.86	3.32	44
46	...	4.60	3.40	5.85	10.40	7.78	3.32	7.97	9.26	5.71	46
Over sandstones and shales, limed											
3	150	9.02	a46.00	...	a11.25	17.44	...	...	5.24	8.18	3
5	250	9.40	b34.59	...	7.14	29.67	...	...	6.35	2.54	5
7	...	5.97	39.07	...	9.00	33.83	...	...	7.08	6.64	7
9	150	12.02	19.00	...	13.88	16.20	...	...	9.95	13.26	9
10	150	3.31	31.03	...	.28	22.98	...	...	1.87	2.49	10
13	200	9.94	21.43	...	9.52	18.77	...	...	6.64	5.32	13
14	200	9.37	23.90	...	7.98	21.13	...	...	5.95	4.76	14
15	200	11.32	24.21	...	3.90	20.78	...	...	6.72	5.38	15
36	150	4.30	5.53	...	1.89	11.24	...	...	4.25	5.27	36
39	...	3.00	34.10	...	6.65	24.33	...	...	3.54	5.31	39
41	300	4.90	21.20	...	7.67	20.03	...	...	4.48	4.48	41
43	...	...	6.49	...	14.31	23.32	...	...	6.57	4.28	43
45	...	...	3.91	...	12.06	12.04	...	...	14.93	5.60	45
47	...	9.40	6.56	...	13.57	11.80	...	...	10.43	8.70	47

Table XIX.—Part II (*Continued*). Basic Yields, Gain from Liming, Superphosphate Applied and Increase

Test No.	*Wheat*		*Hay*			*Value Basic yield Dol.*	*Gain for liming*		*Gain for phosphate*		*Test No.*
	Superphosphate		*Basic yield Cwt.*	*Gain for liming Cwt.*	*Gain for phosphate Cwt.*		*Per acre Dol.*	*Per ton limestone Dol.*	*Per acre Dol.*	*Per 100 lb. phosphate Dol.*	
	Applied Lb.	*Increase Bu.*									
						Over limestones					
22	120	5.10	17.39	3.75	6.42	14.37	1.71	3.42	4.25	4.72	22
23	200	12.07	22.98	4.36	10.21	22.64	1.14	2.28	8.98	7.19	23
24	200	11.46	27.85	...	8.85	27.83	...	...	7.45	5.96	24
25	...	...	22.36	4.59	8.81	26.24	1.51	3.02	6.92	5.53	25
26	200	10.64	19.48	.72	6.47	18.91	.63	.94	6.57	4.92	26
27	160	8.87	29.27	...	4.83	26.60	...	...	5.17	6.46	27
28	120	6.78	19.67	3.41	6.95	18.37	c1.10	3.30	5.89	7.37	28
29	200	7.70	28.00	4.27	3.89	21.88	2.15	4.30	4.56	3.65	29
30	200	5.01	10.21	9.48	3.14	10.41	4.01	8.02	4.26	3.41	30
31	300	4.50	24.35	2.31	7.75	18.32	2.24	4.48	5.47	3.64	31
32	300	5.88	13.19	3.14	10.62	12.14	2.10	4.20	8.67	5.78	32
33	377	9.39	21.20	...	14.80	17.50	...	...	10.16	8.08	33
37	225	7.10	14.60	5.50	11.66	12.41	3.13	6.80	9.21	8.18	37
38	225	5.10	18.12	...	10.83	16.99	...	...	6.50	5.77	38
48	...	3.20	14.36	11.90	7.55	16.85	5.12	12.80	4.55	3.80	48
49	...	7.60	28.16	...	8.36	21.37	...	...	5.11	4.25	49
50	...	1.40	17.45	8.84	1.77	19.07	3.35	8.81	1.11	.92	50
51	...	6.80	20.91	...	9.32	19.82	...	...	4.58	3.82	51
52	...	2.20	5.47	17.67	1.77	13.72	7.53	19.30	1.79	1.47	52
53	...	5.60	23.14	...	8.33	21.25	...	...	4.13	3.44	53
34	250	5.40	26.24	6.73	2.31	21.20	1.28	5.11	2.51	1.47	34
20	200	—.80	40.37	—1.89	2.73	33.70	—1.21	—2.42	...	...	20
21	200	3.22	41.16	...	5.13	31.50	...	...	2.31	1.85	21
54	160	5.47	39.59	...	3.75	65.60	...	...	7.02	6.58	54
55	160	7.46	32.86	...	2.96	41.88	...	...	3.15	2.95	55
56	200	8.92	33.86	...	2.80	35.64	...	...	4.84	3.63	56
57	200	10.47	15.68	...	7.75	19.07	...	...	8.61	6.46	57
58	...	11.46	23.92	...	10.50	19.84	...	...	10.22	6.39	58
59	...	7.47	43.96	...	8.16	37.94	...	...	7.68	4.80	59
60	...	8.80	7.38	8.05	14.51	10.44	2.35	4.70	14.40	12.00	60
61	...	8.80	9.86	21.36	6.16	15.14	10.30	23.00	8.16	7.70	61

a—Two crops; b- 250 lbs. superphosphate on clover; c—Limestone 1 ton per acre.

TABLE XIX.—SUMMARY OF EXPERIMENTS IN LIMING AND FERTILIZING FIELD CROPS GROWN IN ROTATION

PART III: EFFECT OF ADDING POTASSIUM TO PHOSPHORUS IN THE FERTILIZER. EQUIVALENT ANNUAL ADDITION OF MURIATE OF POTASH PER ACRE AND INCREASE OVER THAT DUE TO SUPERPHOSPHATE

TEST No.	Station	*Muriate potash Lb.*	*Annual increase and value per acre*						*Test No.*
			Corn Bu.	*Oats Bu.*	*Soys Bu.*	*Wheat Bu.*	*Hay Cwt.*	*Value Dol.*	
Cereal rotations over sandstones and shales, unlimed									
1	Wooster, Ohio	52	3.85	2.79	...	1.78	a4.97	1.94	1
2	Wooster, Ohio	52	10.04	5.00	...	1.67	a7.87	3.39	2
8	Strongsville, Ohio	52	—.95	.17	...	.90	—2.33	—.24	8
16	Belmont Co., Ohio	12	—3.37	...	...	1.74	a2.23	.20	16
17	Washington Co., Ohio	22	2.27	...	—.53	.41	—.05	.37	17
19	Carpenter, Ohio	13	2.22	...	...	1.63	1.54	1.58	19
35	Scottsburg, Ind.	16	1.30	...	...	.90	3.59	1.44	35
44	Fariston, Ky.	67	3.90	...	.76	...	1.71	1.76	44
Cereal rotations over sandstones and shales, limed									
3	Wooster, Ohio	52	16.03	6.90	...	2.58	a7.75	4.83	3
5	Wooster, Ohio	20	3.80	4.22	...	1.16	3.14	2.05	5
9	Strongsville, Ohio	52	1.15	.70	...	1.48	—5.66	—.07	9
10 b	Strongsville, Ohio	52	7.00	—1.90	...	2.38	2.20	2.24	10
13	Trumbull Co., Ohio	10	1.45	.62	...	.91	—2.39	.36	13
14	Mahoning Co., Ohio	10	1.42	4.82	...	2.23	.54	1.67	14
15	Mahoning Co., Ohio	10	1.13	...	.67	.87	2.69	1.15	15
36	Scottsburg, Ind.	16	3.70	...	...	2.70	2.59	2.63	36
45	Fariston, Ky.	67	...	...	.79	...	4.18	1.23	45

TABLE XIX.—PART III (*Continued*)

TEST No.	*Station*	*Muriate potash Lb.*	*Annual increase and value per acre* *Corn Bu.*	*Oats Bu.*	*Soys Bu.*	*Wheat Bu.*	*Hay Cwt.*	*Value Dol.*	*Test No.*
	Cereal rotations over limestones								
22	Hancock Co., Ohio	15	2.98	—.10	...	1.38	2.27	1.35	22
23	Miami Co., Ohio	22	2.89	3.39	...	3.26	—.53	2.14	23
24	Miami Co., Ohio	22	2.73	...	.88	2.60	—.18	1.66	24
25	Miami Co., Ohio	22	a5.95	2.21	...	...	2.86	1.89	25
26	Miami Co., Ohio	23	8.09	...	...	6.14	1.41	4.98	26
27	Madison Co., Ohio	40	a6.11	...	...	2.86	2.12	2.43	27
28	Germantown, Ohio	13	6.24	...	...	2.53	1.11	2.94	28
29	Hamilton Co., Ohio	22	7.02	...	1.17	.93	2.17	2.46	29
30	Clermont Co., Ohio	22	10.66	...	1.42	2.49	2.90	3.88	30
31	State College, Pa.	100	3.50	3.76	...	.75	7.81	2.57	31
32	State College, Pa.	100	5.42	5.05	...	3.27	11.48	4.46	32
33	Blacksburg, Va.	50	3.25	...	...	.68	—8.88	—1.88	33
34	d Newark, Del.	67	28.90	e3.90	f8.95	6.90	14.54	7.41	34
	Potato and Tobacco rotations								
			Potatoes Bu.			*Wheat Bu.*	*Hay Cwt.*	*Value Dol.*	
54	Wooster, Ohio	67	15.70	...	...	1.39	—.13	4.74	54
55	Wooster, Ohio	67	40.83	...	...	2.39	1.93	12.27	55
56	Hamilton Co., Ohio	33	10.14	...	...	2.73	1.07	4.06	56
57	Clermont Co., Ohio	33	11.71	...	...	5.43	2.29	5.84	57
			Tobacco Lb.			*Wheat Bu.*	*Hay Cwt.*	*Value Dol.*	
58	Germantown, Ohio	60	3.64	...	...	3.67	4.74	8.54	58
59	Miami Co., Ohio	60	1.08	...	...	.10	1.14	2.07	59
60	Greenville, Ky.	50	.53	...	...	—.10	3.66	1.57	60
61	Mayfield, Ky.	50	—.16	...	...	—4.70	—4.08	—3.04	61

a—Two crops; b—raw phosphate as basic treatment; d—coastal plains soil; e—first 6 years; f—last 8 years.

TABLE XIX.—SUMMARY OF EXPERIMENTS IN LIMING AND FERTILIZING FIELD CROPS GROWN IN ROTATION

PART IV: EFFECT OF ADDING NITROGEN TO PHOSPHORUS AND POTASSIUM IN THE FERTILIZER. EQUIVALENT ANNUAL ADDITION OF NITRATE OF SODA PER ACRE AND INCREASE IN EXCESS OF THAT DUE TO SUPERPHOSPHATE AND MURIATE OF POTASH COMBINED

Test No.	Station	Nitrate soda Lb.	Annual increase and value per acre						Test No.
			Corn Bu.	*Oats* Bu.	*Soys* Bu.	*Wheat* Bu.	*Hay* Cwt.	*Value* Dol.	
	Cereal rotations over sandstones and shales, unlimed								
1	Wooster, Ohio	96	4.39	8.54	. . .	6.51	[a]9.98	4.38	1
2	Wooster, Ohio	96	5.47	7.74	. . .	8.58	[a]8.95	4.87	2
8	Strongsville, Ohio	96	3.50	4.07	. . .	2.16	1.14	2.06	8
16	Belmont Co., Ohio	30	3.32	. . .	. . .	1.19	[a]6.50	2.01	16
17	Washington Co., Ohio	40	1.04	. . .	.31	3.39	1.75	1.65	17
19	Carpenter, Ohio	53	3.93	. . .	. . .	3.15	1.97	2.76	19
35	Scottsburg, Ind.	80	1.60	. . .	. . .	2.80	—1.37	1.55	35
44	Fariston, Ky.	50	—3.10	. . .	—1.24	. . .	—4.35	—2.21	44
	Cereal rotations over sandstones and shales, limed								
3	Wooster, Ohio	96	4.42	2.60	. . .	5.86	[a]4.53	2.98	3
5	Wooster, Ohio	27	2.15	1.21	. . .	5.89	.96	2.56	5
9	Strongsville, Ohio	96	2.54	2.39	. . .	2.90	1.37	1.92	9
10	[b] Strongsville, Ohio	96	—.41	7.54	. . .	5.61	1.23	2.79	10
13	Trumbull Co., Ohio	27	.62	1.00	. . .	.86	1.42	.73	13
14	Mahoning Co., Ohio	27	4.71	1.24	. . .	1.55	1.30	1.77	14
15	Mahoning Co., Ohio	27	2.66	. . .	1.62	1.47	3.34	2.10	15
36	[c] Scottsburg, Ind.	27	—.80	. . .	. . .	.30	—4.41	—1.63	36

TABLE XIX.—PART IV *(Continued)*

TEST No.	Station	*Nitrate soda Lb.*	*Annual increase and value per acre*					*Value Dol.*	*Test No.*
			Corn Bu.	*Oats Bu.*	*Soys Bu.*	*Wheat Bu.*	*Hay Cwt.*		
			Cereal rotations over limestones						
20	Paulding Co., Ohio	40	3.28	3.24	. . .	4.57	.79	2.61	20
21	Paulding Co., Ohio	40	2.46	. . .	.52	2.00	.20	1.34	21
22	Hancock Co., Ohio	40	—.85	—.43	. . .	—.92	—1.13	—.68	22
23	Miami Co., Ohio	40	—3.90	1.97	. . .	—.58	.32	—.66	23
24	Miami Co., Ohio	40	—2.38	. . .	—1.24	1.03	—1.60	—.86	24
25	Miami Co., Ohio	40	a —1.59	—1.46	. . .	. . .	—2.45	—.87	25
26	Miami Co., Ohio	43	—1.51	. . .	. . .	.60	1.15	.06	26
27	Madison Co., Ohio	15	. . .	. . .	. . .	.08	.65	.12	27
28	Germantown, Ohio	53	2.05	. . .	. . .	2.09	—.76	1.26	28
29	Hamilton Co., Ohio	40	.24	. . .	—.11	1.62	1.98	.81	29
30	Clermont Co., Ohio	40	3.52	. . .	.74	4.49	2.92	2.82	30
31	State College, Pa.	150	1.16	.08	. . .	3.82	.76	1.00	31
32	State College, Pa.	150	5.50	.96	. . .	3.37	2.22	1.36	32
33	Blacksburg, Va.	77	4.02	. . .	. . .	1.77	15.20	4.85	33
34	d Newark, Del.	87	6.05	e3.60	f4.10	6.20	6.55	5.15	34
	Potato rotations		*Potatoes Bu.*			*Wheat Bu.*	*Hay Cwt.*		
54	Wooster, Ohio	53	—6.48	. . .	. . .	1.98	1.26	.65	54
55	Wooster, Ohio	53	.16	. . .	. . .	.77	3.36	1.03	55
56	Hamilton Co., Ohio	33	2.61	. . .	. . .	—1.91	—3.87	—.87	56
57	Clermont Co., Ohio	33	—8.06	. . .	. . .	—3.98	—3.05	—4.42	57
	Tobacco rotations		*Tobacco Lb.*			*Wheat Bu.*	*Hay Cwt.*		
58	Germantown, Ohio	80	—3.88	. . .	. . .	—10.95	—10.63	—13.15	58
59	Miami Co., Ohio	80	.36	. . .	. . .	.87	—2.73	.42	59
60	Greenville, Ky.	100	.11	. . .	. . .	.10	—4.86	—.75	60
61	Mayfield, Ky.	100	1.44	. . .	. . .	3.70	7.48	5.44	61

a—Two crops; b—raw phosphate as basic treatment; c—nitrogen in mixed fertilizer; d—coastal plains soil; e—first 6 years; f—last 8 years.

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